Recent advances in graphene-derived materials for biomedical waste treatment

Recent Advances in Graphene-Derived Materials for Biomedical Waste Treatment

Kehinde Shola Obayomi [a], Sie Yon Lau [a*], Ibitogbe Enoch Mayowa [b], Michael K. Danquah [c], Jianhua Zhang [d], Tung Chiong [a], Louise Meunier [e], Mohammad Mahmudur Rahman [f,g]

[a] Department of Chemical Engineering, Curtin University, CDT 250, 98009 Miri, Sarawak, Malaysia

[b] Department of Civil Engineering, College of Engineering, Landmark University Omu-Aran, PMB 1001, Kwara State, Nigeria

[c] Department of Chemical Engineering, University of Tennessee, Chattanooga 615 McCallie Ave, Chattanooga, TN 37403, United States

[d] Institute for Sustainable Industries and Liveable Cities, Victoria University, Werribee, VIC 3030, Australia

[e] Department of Chemical Engineering, Queen's University, Kingston, K7L 3N6, Canada

[f] Global Centre for Environmental Remediation (GCER), College of Engineering, Science and Environment, The University of Newcastle, Callaghan, NSW 2308, Australia

[g] Department of General Educational Development, Faculty of Science and Information, Technology, Daffodil International University, Ashulia, Savar, Dhaka - 1207, Bangladesh

*Corresponding Author

Tel.: +6085630100 Ext.: 2418

E-mail: johnlsy@curtin.edu.my

Full postal address: Department of Chemical Engineering, Curtin University Malaysia, CDT 250, 98009 Miri, Sarawak.

Abstract

Untreated biomedical wastes discharged into water bodies, primarily by hospitals and health care facilities; release a wide range of contaminants that poses danger to human health and environmental sustainability. Therefore, developing sustainable and dependable treatment methods for biomedical waste is a top priority. Nano-sized graphene is known to have excellent unique properties including high current density, optical, mechanical, thermal conductivity, high chemical stability, high surface area and chemical stability. Graphene-based nanomaterials and derivatives as a result of their excellent properties have received increased attention in wastewater treatment in recent years. Despite significant progress in the production of graphene at laboratory scale, there is a need to focus on green large-scale graphene synthesis to pave the way for adopting graphene-based technology on an industrial scale. In wastewater treatment, advanced development of pure graphene on various significant functionalization exhibits excellent adsorption efficiency when functionalized when compared to other alternatives. Top-down as well as bottom-up approaches such as chemical vapour deposition, and chemical exfoliation among other approaches can be used for graphene synthesis and functionalization. As a result, the benefits of graphene oxide-based nanomaterials have been unraveled in the treatment of biomedical wastewater. Adsorption and photocatalysis techniques have sparked widespread interest because they allow for the environmentally friendly treatment of biomedical wastewater, and significant progress has been made in recent years. This study examined the graphene synthesis method and the use of graphene oxide-based nanomaterials as adsorbents and photocatalysts in the treatment of biomedical waste. Furthermore, the recyclability, thermal stability, and future perspectives on the directions and difficulties in graphene-based material synthesis are summarized.

Keywords: Graphene; Graphene synthesis; Graphene-based nanomaterials; Biomedical waste; Waste treatment; Adsorption; Photocatalysis; Mechanism

1. Introduction

With the innovative development of advanced biomedical technology, new challenges, such as biomedical waste management, are being created (Agrawal et al. 2021; Saravanan et al. 2022). Biomedical wastes (BMW) are mostly generated by pharmaceutical industries, healthcare facilities, medical and educational research institutions, nursing homes, and hospitals during medical treatment of human and veterinary populations as presented in Fig. 1. They include expired vaccines and drugs, blood products, tissues, organic fluids, radioactive waste, and chemical and pharmaceutical residues. BMW may also contain chemical, surgical, pharmaceutical, cytotoxic and other biological waste materials which are potentially hazardous to living organisms including humans and the environment (Dash et al. 2021; Sohal et al. 2021). Inadequate BMW management can have consequences, such as increasing infectious diseases, resulting from groundwater contamination (Ara et al. 2022). It has been established that even trace amounts of various drug residues can exist in surface, ground and even drinking water (Komal et al. 2022). The remainder of drugs that undergo partial metabolism in the human body is discharged as effluent into receiving water bodies. A large majority of such drugs is antibiotics of which about 80–90% return to the environment via excretion in their parent form due to their robust molecular structure, making them to degrade naturally (Al-Jubouri et al., 2022).

Several conventional and advanced techniques, such as electrochemical treatments, filtration, precipitation, membrane separation, photocatalysis, ion-exchange, reverse osmosis and adsorption, have been used for treatment of antibiotics in wastewater (Khanday et al. 2019; Grisales-Cifuentes et al., 2021; Qin et al., 2022). However, they still face challenges of cost-effectiveness, environmental friendliness, and process efficiency from material preparation to process optimization (Lee et al. 2019). Graphene and its derivatives have impacted wastewater treatment and have been utilized in photocatalysis, adsorption or as an effective electrode in various treatment technologies and applications (Obayomi et al., 2022; Yang et al., 2022; Han et al., 2022). Adsorption have numerous advantages such as its high efficacy, low cost, and ecological viability to remove organic contaminants from water (Zhu et al., 2018; Januário et al., 2022; Zhu et al., 2022).

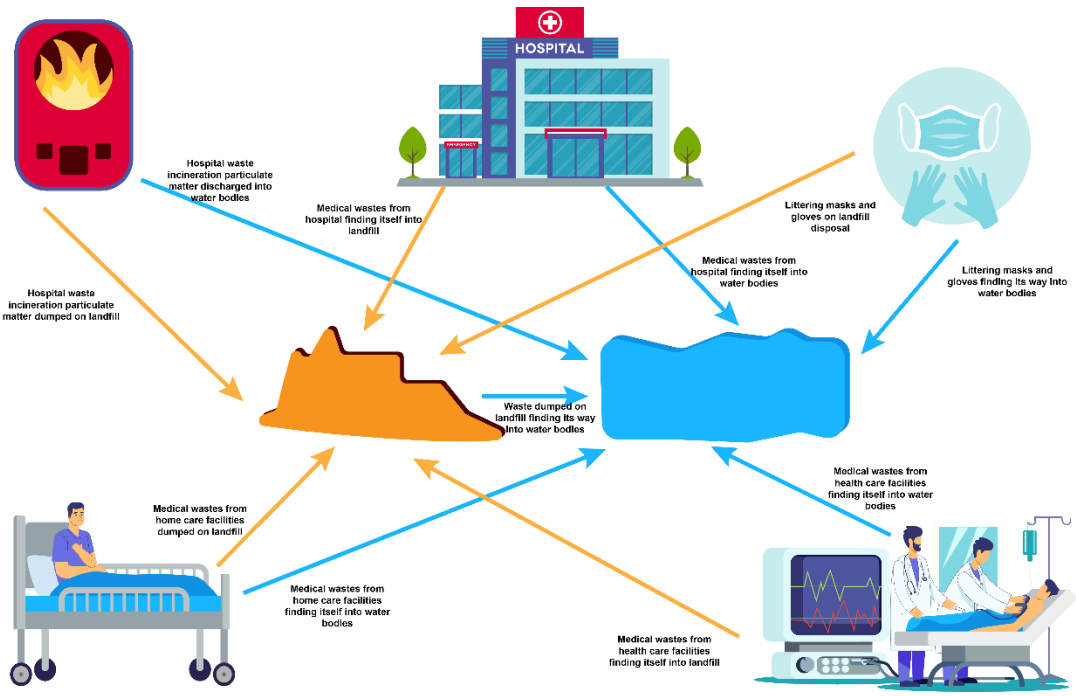


Fig. 1. Biomedical waste discharged channels into water bodies

Graphene is a planar single-atom layer thick sheet and two-dimensionally structured material composed of tightly packed sp2-bonded carbon atoms in a honeycomb crystal lattice with a distinct charge mobility carrier, a broad electrochemical spectrum, and physicochemical properties (Zhang et al., 2021; Reddy et al., 2022; Jia et al., 2022). As a result of its outstanding optical, thermal, electrical and mechanical properties as well as its high specific surface area, graphene has emerged a revolutionary material with wide range of applications, including its use as innovative adsorbents for water treatment (Igbal et al. 2020; Qu et al., 2022). It's an excellent adsorbent for removing a wide range of inorganic and organic pollutants because of its high surface area, abundance of active sites and excellent delocalized electron systems (Hossain et al., 2020). Despite significant progress made in the development and application of grapheme-based adsorbents, some inherent disadvantages remain.

The hydrophobic nature of its surface and ease of aggregation in hydrous solution are disadvantages of graphene both of which significantly reduce its adsorption capacity in practical applications (Li et al. 2019). During liquid processing graphene even rolls to form graphite. Aggregation can limit its adsorptive application by blocking active sorption sites, decreasing theoretical surface area and impeding rapid mass transport (Phoon et al., 2020). Functionalized graphene can be designed to address some of these limitations. It is essential to understand the

adsorption efficiency of graphene-based materials and how it correlates to the mechanisms of interaction between adsorbents and contaminants in order to advance the development of its functionalized composites and their applications in waste treatment (Wang et al., 2021a). As a result of their high surface area and abundance of active sites, there has been considerable interest in graphene-based materials as potential adsorptive pollutants removal from water. The underlying adsorption mechanisms are used for creating graphene-based adsorbents for target pollutants. Reports on composite GO and semiconductor photocatalytic materials have increased in recent years and GO as a good carrier for photocatalysts has improved the properties of materials developed (Zhang et al. 2020; Liu et al. 2012). GO/Ag_3PO_4 composite material and the GO sheet was coated with Ag_3PO_4 nanoparticles. In photocatalytic degradation experiments, composite materials outperform pure Ag_3PO_4 in photocatalytic performance. This chapter discusses recent advances in the graphene synthesis and graphene-based materials and its applications in biomedical treatment via adsorption and photocatalytic methods. The present review begins with the synthesis, adsorptive and photocatalytic treatment, isotherm and kinetic study, reusability and mechanisms of graphene-based materials in biomedical waste treatment. This review is expected to provide relevant existing knowledge and stimulate fresh ideas for the development of safe and efficient graphene nanomaterials-based biomedical devices. With the development of graphene nanoparticles, numerous other cutting-edge materials will also surely be found, and numerous futuristic technologies will also become feasible.

2. Synthesis of graphene nanostructures

The extraordinary electronic, surface, mechanical and optoelectronic attributes (properties) of 2-dimensional graphene- a crystal lattice of carbon atoms are intriguing, making it possible to develop various innovations across a broad spectrum of industries (Lim et al., 2018; Ikram et al., 2020). The term "graphene synthesis" refers to any process, whether chemical or mechanical, that is used to produce graphene with the desired level of purity and dimensions of the finished product (Somasekaran et al., 2022). Currently, graphene synthesis processes can be classified into two types namely; top-down and bottom-up (Kumar et al., 2021; Reddy et al., 2022). The graphical illustration of the Top-down and Bottom-down synthesis approach is presented in Fig. 2.

2.1 Top-down approach

2.1.1 Mechanical exfoliation

A well-known and scientific way to mono-layered graphene-flakes extraction on preferred substrates is mechanical exfoliation. It is formed when layered materials are subjected to transverse or longitudinal stress (Yi and Shen, 2015; Ikram et al., 2020). Mechanical exfoliation is also regarded as a low-cost method of synthesizing graphene. Graphene can be fabricated by stacking single graphene carbon atoms using van der Waals forces with bonding energy and inter-spatial values of 2 eV/nm^2 and 3.34Å respectively (Bhuyan et al., 2016). Mechanical cleaving, on the other hand, involves an external force of about 3 μN/mm^2 for the separation of mono-atomic layer from graphite. Sheet stacking is caused by a partially filled *p*-orbitals overlapping perpendicularly on the sheet's plane with van der Waals forces inclusive (Zhang et al., 2005). Exfoliation is the inverse of stacking and results in weak bond strength as well as wide vertical lattice spacing. It does, however, results in bond improvement and tiny lattice spacing in the hexagonal lattice plane (Gao et al., 2018). Several materials made from such as natural Gr (Lin et al. 2017), highly ordered pyrolytic Gr (Zho et al. 2016). Graphene sheets Synthesis with different thicknesses alongside mono-crystal Gr, have been observed as a result of mechanical exfoliation (Assouik et al., 2016). The exfoliation method used scotch tape (Lin et al., 2013a), ultra-sonication (Compton et al., 2012), transfer printing technique (Song et al., 2017), and electric field (Santos and Kaxiras, 2013). Mechanical exfoliation has the disadvantage of producing a low yield of graphene

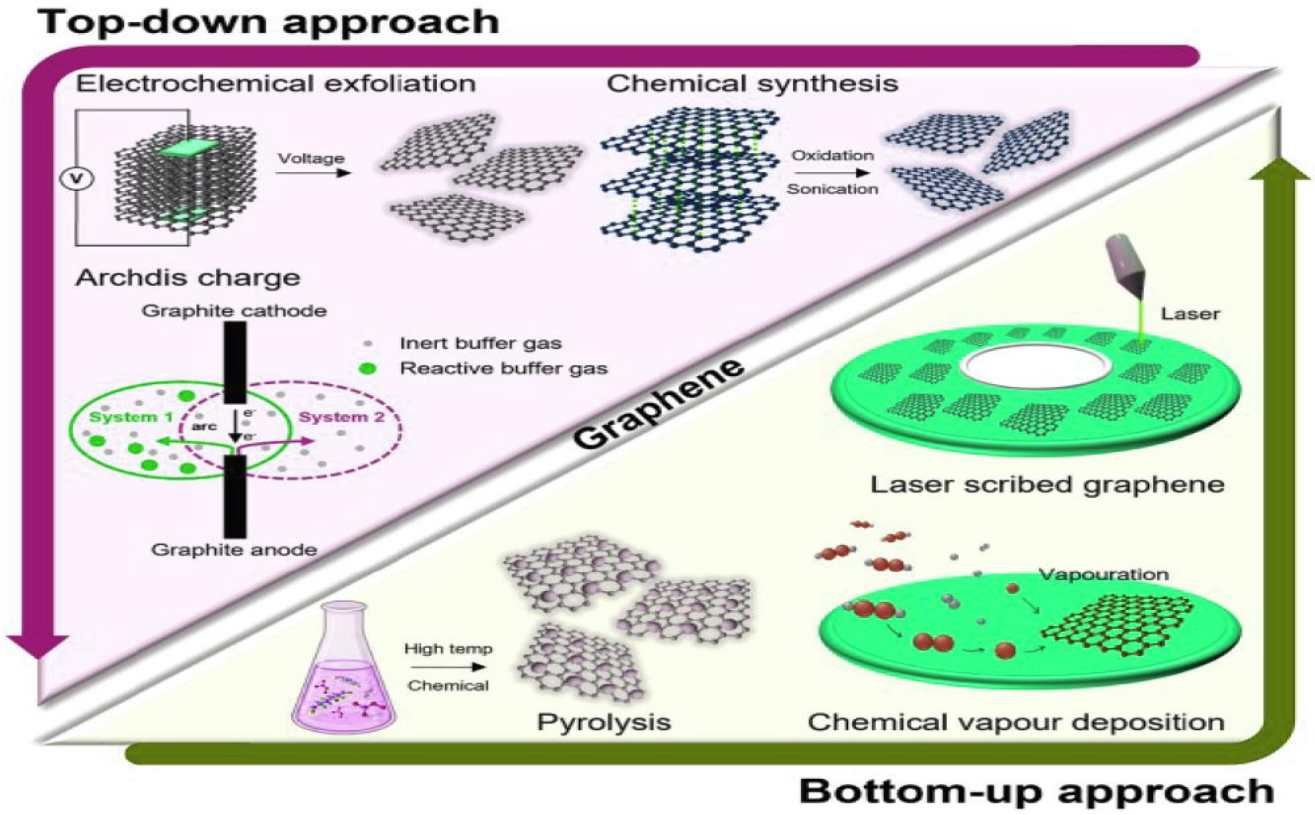


Fig.2. Graphical illustration of the Top-down and Bottom-down synthesis approach (Source: Reddy et al., 2022)

2.1.2 Chemical reduction

Another top-down technique for producing graphene is chemical reduction of graphite-oxide. Graphite-oxide is always produced by oxidizing graphite. Oxidants like $KMnO_4$, H_2SO_4 and nitric acid can be used to perform oxidation (Lim et al., 2018). GO reduction and sonication are also alternatives to graphene synthesis (Shin et al., 2009). Alkaline solution, ascorbic, hydrazine, glucose, hydroquinone, pyrrole, hydroxylamine, and phenyl hydrazine are some other reducing agents that can be used (Zhang et al. 2010; Stankovich et al., 2007; Wang et al. 2008; Zhou et al. 2011). The hydrophilic nature of GO makes it a potentially useful material. In other to fabricate a mono-layered or double-layered GO, GO is first suspended in H_2O using sonication followed by surfaces deposition by filtering or spin coating (Iqbal et al., 2020). As a result, graphene films can be synthesized by thermally or chemically reducing GO. Furthermore, to create reduced GO dispersions in the non-polar solvents, a straightforward method like ‘solvo thermal reduction’ is advantageous. Although this process allows for mass production, it is difficult to produce a high-quality product due to the presence of some accompanying defects at the edges and deformation

(Paredes et al., 2011). Environmentally friendly approaches to limiting the utilization of hazardous chemicals have grown in popularity in recent years (Aunkor et al., 2016). For instance, reducing agents, such as ascorbic acid, have been used to create a benign synthesis process (Bo et al., 2014). Electrochemical reduction is another method that can be utilized for large-scale graphene synthesis. This procedure removes a huge number of oxygen functional groups while also improving functional and electrical properties (Mohan et al., 2016). Thermal reduction of GO, in addition to chemical and electrochemical reduction, is regarded as an efficient method for producing high-performance rGO powders (Wu et al., 2011). The process (reduction) takes place in an unreactive environment at a high heating rate. GO undergoes reduction by evaporating and burning water molecules and oxygen functional groups at high temperatures (above or near 1000 °C). The pressure generated by the heating process determines the effectiveness of thermal reduction (Tang et al. 2011).

2.1.3 Chemical exfoliation

Chemical exfoliation

Another efficient top-down method of graphene synthesis is chemical exfoliation. Chemical exfoliation is divided into two steps. First, van der Waals forces reduction between the inter-layers thereby increasing the Gr interlayer spacing. Second, a rapid heating process for Gr exfoliation into single-layers and few-layers (Lim et al., 2018). The Brodie (Brodie, 1859), Staudenmaier (Staudenmaier et al., 1898), and Hummers (Hummers and Offeman, 1958) techniques have been used to create GOs. The Hummers method evolved, giving rise to modified and improved Hummer’s method (Chen et al., 2013). Table 1 compares the differences, types of oxidants used, toxicity, and potential benefits of the different methods. The main benefit of Hummer's method is scalable and low economic cost. The method is useful in producing large-scale graphene sheets, making it suitable for industrial applications. Hummer’s method is also a fast synthetic process, which makes it ideal for mass production. The improved Hummers technique is preferred to make graphene because it has low free toxicity and can make more organized graphene structures (Obayomi et al., 2022).

202 Table 1. Chemical exfoliation methods for graphene synthesis: -overview

Method	Oxidants used	Toxicity	Advantage	Disadvantage	References
Brodie method	HNO_3& $KClO_3$	Yes	-Laid principle for the delamination of Gr in G sheet by oxidation.	-Risk of explosion due to $KClO_3$ usage. - Slow recovery progression - Product dispersibility in basic solution, small size, limited thickness, and imperfect structure	Brodie (1859); Botas et al. (2013)
Staudenmaier method	HNO_3, H_2SO_4, & $KClO_3$	Yes	-Single step -Oxidation process. - Improved Process efficiency.	- Slow process. - Requires high operational temperature. - Bears risk of explosion. -Toxic	Staudenmaier (1898); Ikram et al. (2020)
Hummer's method	H_2SO_4 $NaNO_3$ & $KMnO_4$	None (NO_x is released)	-Operates at low temperature. -The process is fast and efficient. -No Chances of explosion -Suitability for large scale GO production. -When compared to the Brodie and Staudenmaier methods, the oxidation level is higher. -Acid fog formation elimination. -Within hours, the reaction was completed.	-Incomplete oxidation. -Difficulties in removing of residual Na^+ and NO_3^- ions from wastewater. -Purification and separation are both time-consuming processes. -Toxic gases are generated. -Low yield of product.	Hummers and Offeman (1958); Bota et al. (2013); Talyzin et al. (2017)
Modified Hummers method	H_2SO_4 $NaNO_3$ and $KMnO_4$ or H_2SO_4 and $KMnO_4$	None (NO_x is released)	-Improved oxidation level enhances the GO performance. -Increased reaction yield. -Toxic gas emissions were reduced.	-Exhausting procedures for purification and separation are involved. - The process is time consuming.	Chen et al. (2013); Ikram et al. (2020)
Improved Hummers method	H_2SO_4, H_3P0_4 and $KMnO_4$	None	-More organized structured GO is produced. -The basal plane defect was minimal -The procedure is eco-friendly. -No toxic gases produced. - High GO yields. -The same level of conductivity results from same oxidation level.	-Purification and separation processes can be very laborious and lengthy.	Chen et al. (2013); Lim et al. (2018) Ikram et al. (2020)

203 (Source: Obayomi et al., 2022)

204

205 2.1.4 Liquid phase exfoliation.

206 Liquid phase exfoliation is a method widely used for graphene synthesis. This synthesis process is

207 broken down into three main phases: first, the graphene derivatives to be produced are dispersed

in a suitable solvent; next, the graphene is exfoliated; and finally, the derivatives of exfoliated graphene are separated from their parent material during purification step (Niu et al., 2016). The appropriateness of the solvent can be evaluated based on its "surface tension," "surface energy," and "Hildebrand and Hansen solubility," among other characteristics. As a result, graphene dispersion can be achieved by making use of a wide range of aqueous and non-aqueous liquids (Hernandez et al., 2008). Typically, for graphene exfoliation, the ideal surface tension is 0.4–0.5 J/m^2 and surface energy is 0.70–0.8 J/m^2 for the solvent. Because they have surface energies similar to that of graphite, they have lower mixing enthalpy and thus a simpler process exfoliation (Yi and Shen, 2015). Brodie began graphite production using solvent made from potassium chlorate ($KClO_3$) and nitric acid (HNO_3) and oxidized graphite to produce GO. Staudenmaier successfully extracted oxidized GO using the same solvent (Fang et al., 2009). Their method, however, has become unpopular because of lengthy processing time and the use of potassium chlorate which is hazardous. Hummers created GO in concentrated sulphuric acid (H_2SO_4), potassium permanganate ($KMnO_4$) and sodium nitrate ($NaNO_3$) solvents (Hummers & Offeman, 1958). However, the GO produced through this method is more oxidized than previous methods and the presence of non-oxidized graphite core in the GO necessitates a pre-treatment for the improvement of the oxidation process (Kovtyukhova et al., 1999). Also, Hernandez et al. (2010) investigated solvent's effect on graphene production using over 40 different solvents. An extremely efficient method for producing graphene with minimal solvent was developed by the researchers. Although liquid phase exfoliation is a common method of producing graphene, sonication can cause some defects on the edge and basal planes (Iqbal et al., Amiria et al., 2018). Sonication time is important because it affects graphene concentration. It was previously found that the more prolong the duration of sonication, the greater the graphene concentration (Hernandez et al., 2010). In graphene exfoliation, centrifugal force is also important. High centrifugal force produces thinner graphene flakes (Ciesielski and Samori, 2014). The liquid exfoliation process results in defects on graphene that can be reduced by adjusting the sonication time, temperature, and intensity (Amiria et al., 2022).

2.1.5 Electrochemical exfoliation

Chemical or mechanical graphene synthesis has several processing limitations, including a time-consuming and labor-intensive procedure, the use of hazardous and environmentally harsh solvents/reagents and their regularity in quality as well. Though the processes for producing high-

quality graphene have been proposed, such as thermal decomposition of silicon carbide (SIC), micromechanical cleavage and CVD, relatively low production rates and high costs, make them they impractical for commercial applications. Electrochemical exfoliation proves to be a suitable method for bulk synthesis of graphene in less time and at minimal cost. It is safer because no harsh chemicals are used in this process. It is a method of using an electrical current to exfoliate a graphite electrode in a liquid electrolyte. In this process, the working electrode is usually a graphite film/rod /highly oriented pyrolytic graphite sample. Another counter electrode made of the same graphite/nickel/iron/platinum alloy could be used. Migration of ions (+ve charged) from the electrolyte to the working electrodes is caused by a potential difference created between two electrodes, and become interposed among the graphene layers of graphite. This process known as intercalation produces the impetus to disband the van der Waals forces, resulting in the expansion of graphite structurally. The graphite electrodes properties such as particulate size, layer arrangements, defects, thickness and appropriate pre-treatment, is also expected to influence ion intercalations (Aghamohammadi et al., 2020; Nayak et al., 2022)

2.2 Bottom-up-approach

2.2.1 Epitaxial growth on silicon

Epitaxial growth is known as the growth layer of a substance on a substrate that continues the crystal structure of the substrate. There is tendency for silicon carbide wafer to sublime when subjected to specific conditions: high temperatures at 800 to 1150 °C and vacuum conditions at 109 to 1010 mbar or at 1500 °C under noble argon gas. Hence, leaving the carbon remaining on the substrate to form graphitic layers on the wafer's carbon or silicon faces (Kumari, 2021). As one might expect, silicon carbide to have a lattice structure similar to graphene. Unlike chemical vapour deposition (CVD), epitaxial growth enables the production of large surface-area graphene sheets. This is a transfer-free process that is dependent on the substrate’s crystallographic orientation, meaning that transferring the graphene requires no peculiar technique. The mechanism of graphene epitaxial growth consists of two steps: nucleation and layer-by-layer growth (Yazdi et al., 2016). Based on the substrate, there are types of epitaxial growth processes: homo-epitaxial growth and hetero-epitaxial growth. Homo epitaxial growth process normally involves film deposition on same material as the substrate. When the film and substrate are made of different materials, a hetero-epitaxial structure is formed. Silicon carbide was first applied for measuring

electrically on patterned epitaxial layers (Ikram et al., 2020). Edward Goodrich Acheson invented this process in 1893, when he devised a technique for synthesizing silicon carbide (SiC) by heating various carbonaceous sources. At temperature greater than 4000 °C, the author discovered that pure crystalline graphite was formed (Acheson, 1896; Iqbal et al., 2020). As far as large-scale production is concerned, this method looks promising. The epitaxial growth method, on the other hand, has a very high production cost due to its intensive energy features and the prohibitively high cost of single crystal commercially available silicon carbide substrates (Choi et al., 2010). Another significant limitation of this method is non-uniformity. Furthermore, Si-face graphene is preferred over C-face graphene because it has better graphene growth uniformity. Until now, this method has been underutilized due to a lack of knowledge about the growth and interaction mechanisms of graphene and the SiC substrate (Li et al., 2009).

2.2.2 Chemical vapour deposition on metal catalyst

CVD is a straightforward method which utilizes carbon precursors in its gaseous state e.g., methane to produce graphene. High surface area, single-layered and few-layered graphene can be grown on copper substrates (Lim et al., 2018). This method can produce high surface areas of monolayer graphene (a few cm^2). CVD has the potential to develop into a technology that is viable for commercial use. The solubility of carbon in metals is the fundamental premise behind the CVD process. Hydrocarbons and other gaseous carbon precursors are introduced into a reactor that is able to withstand high temperatures. Once inside, the hydrocarbons and other gaseous carbon precursors break down and dissolve into metal substrates (Alshamkhani et al., 2021). The difference in carbon solubility at different temperatures causes carbon to precipitate out of solid carbon-metal solutions. The growth substrate in the CVD process is the most significant aspect in the formation of graphene which starts from hydrocarbon decomposition and succeeded by evolution of metal substrate with carbon atom deposit (Kumari, 2021). It is difficult to transfer graphene to a substrate of interest from the growth substrate because graphene has a low chemical response. As a result, the fabric begins to show flaws and wrinkles (Kumar et al., 2021). In addition, the procedure is complicated and energy-intensive, which restricts the task at times. The CVD process, however, remains the most auspicious high surface-area graphene production technique. In the CVD process, graphene is deposited on different of metal plates (substrates), including Cu, Ni, Ir, Pd, and Ru (Reina et al., 2009; Kim et al., 2009; Coraux et al., 2008; Choucair

et al., 2009). Copper and nickel are the most commonly used substrates for CVD growth of graphene (Bouhafs et al., 2021).

2.2.3 Organic synthesis

Polycyclic hydrocarbons (PAHs) can be used to create graphene, specifically graphene nanoribbons (GNRs). Unlike the CVD method, which produces GNRs with widths of 30–200 nm, GNRs with widths of less than 10 nm can be produced by organic synthesis, making it easier to engineer their band-gaps. Nevertheless, Gr synthesis from polycyclic hydrocarbons is tough because C–C bonds formation is required in a single step as well as the activation of inert C–H bonds in polycyclic hydrocarbons enabling those bonds to participate in the reaction. This makes the process time-consuming and complicated. Notwithstanding, there have been developments in chemical processes that are both quick and efficient (Basagni et al., 2015) with many of them predicated on oxidative cyclodehydrogenation (Scholl reaction) (Salvatierra et al., 2015). Diels-Alder polymerization, cyclotrimerization, and photocyclization are other methods for organic graphene synthesis (Zhang et al., 2010; Liu et al., 2014). These techniques are not only necessitated, there is limitation in the number of products produced.

3. Biomedical waste treatment using graphene

As the world's population expands so is medicines and healthcare products demand to treat diseases. Thus, there is a need to channel resources and technology towards improving and promoting the manufacturing of various pharmaceutical and medical products. However, the lack of proper techniques and the use of sub-optimal approaches to waste minimization during production, post-production and/or treatment stages by pharmaceutical industries or health care facilities generate effluents that are released into the environment untreated (Patel et al., 2022). Sustainable and safe management of biomedical waste is a global challenge because of its potential hazard to human the environment and health. The increased generation of biomedical wastes from various health care facilities, including hospitals, clinics, and nursing homes, has also become a matter of concern in many countries. Removal of toxic metal ions, recalcitrant organic pollutants, and pharmaceuticals by various emerging technologies has been the primary focus of research over the course of the past decade (Majumder et al., 2021). Treatment of biomedical waste can be accomplished in various ways including through the application of physical, chemical, and

biological processes. It is important to consider the type and quantity of waste to be treated when deciding about which of these technologies to employ. Nevertheless, the majority of these techniques including advanced oxidation processes, electrochemical purification, membranes processes, and many more are not eco-friendly and may pose health risks to both employees and the general public as well. Nonetheless, adsorption and photocatalytic methods seems to overcome these challenges which make it more preferred as it outperforms other techniques due to its ease of operation, cost-effectiveness, flexibility, technological feasibility, absence of byproducts, and the ability to be easily recycled. (Cao et al., 2021). The various methods for treatment of biomedical waste using graphene and its derivatives is presented in Fig. 3.

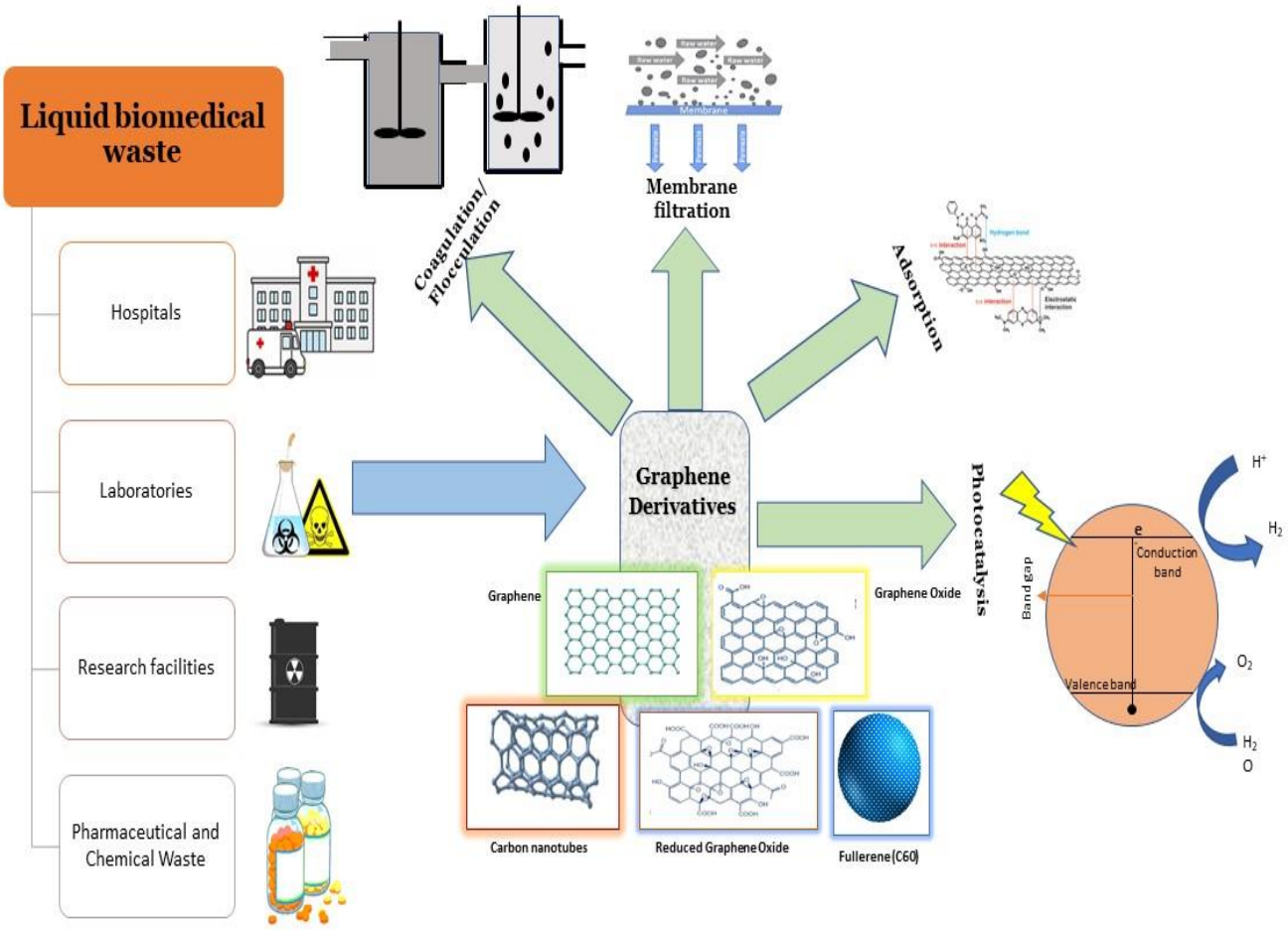


Fig. 3: The various methods for biomedical liquid waste treatment using graphene and its derivatives

3.1 Infectious biowaste treatment

Generally, biomedical waste tends to be cytotoxic, injurious, chemical or infectious. Infectious biomedical waste contains substances which have deleterious effects on biological organisms. Biomedical waste is hazardous since it has the potential to spread infections. Once the waste becomes contaminated with biohazardous agents, they pose the risk of disease transmission. They include waste from lab cultures, isolation wards, equipment that have come in contact with infected patients, infected clinical specimens, tissue from experimental animals, cotton swabs and excreta as well as soiled mattresses and beddings from blood or body fluids (Reddy et al., 2014). Hospital wastewater is a major breeding ground for antibiotic-resistant bacteria, making it a potential vector for human and environmental infection (Amine, 2013; Shahzad et al., 2021). The importance of managing biomedical waste is critical, particularly in medical facilities. This is due to the fact that improper segregation, biomedical wastes disposal, and inclusion of biomedical waste in municipal waste making healthcare workers and the general public vulnerable (Makajic-Nikolic et al., 2019). Hence, infectious biomedical waste management should be a top priority for hospitals and other medical facilities. Although it is common knowledge that efficient wastewater treatment technologies are required to harness the control of infectious waterborne pathogens, it is unfortunate that the present options available for managing biomedical waste do not address the current danger that is posed by liquid effluent discharges, which is a significant issue for healthcare facilities. GO, a function form of graphene with excellent electrochemical properties and functional groups e.g. -COH, -OH, and R-O-R can be applied in wastewater treatment. Although no studies have been reported in literature on the utilization of graphene as an adsorbent for the treatment of infectious biowaste and therefore we proposed that this area of research will be viable and require attention. In environmental fields, attention has been drawn to the use of nanoparticles due to the rapid development of nanotechnology. Effective microbial decontamination and pathogen disinfection is critical to controlling transmission and thereby reducing risk of infection (Rikta, 2021).

Reduced GO possesses antimicrobial properties, which hinders bacterial growth and therefore the biofilm formation on the filter surfaces (Hu et al., 2010). Physical and chemical properties such as stability, reactivity and large surface area makes nanoparticles outstanding and also preferred catalysts and adsorbents (Li et al., 2008; Rikta and Tareq, 2017; Rikta, 2016).

Bao et al., (2011) impregnated GO nanosheets with silver nanoparticles and applied them for microbial disinfection and found them effective for inactivating *Escherichia coli* and *Staphylococcus aureus* with 100% and 87.6 % removal efficiency.

Gollavelli et al. (2013) utilized smart magnetic graphene resulting from graphene oxide and ferrocene precursors to inactivate Escherichia coli with 100 % removal efficiency. Researchers have also suggested possible mechanisms responsible for the destruction and inactivation of microorganisms including- Production of toxic reactive oxygen species (ROS) due to the GO's interaction with wastewater through the cell protein and genetical material damages (Rikta et al, 2019), microbial disinfection is achieved via the Sharp edges present in graphene and GO which aid microorganisms' destruction physically (Smith and Rodrigues, 2015). Additionally, various research has proposed obstruction to nutrients diffusion into microbial cells by graphene sheets causing cell wrapping leading to the suppression in the growth of micro-organisms (Liu et al., 2011; Chen et al., 2014).

3.2 Hazardous biowaste treatment

Hazardous wastes are generated from industries, hospitals some household wastes. Hazardous waste is defined by the United State Resource Conservation and Recovery Act (RCRA) as a of solid-liquid wastes combination that may give rise to or contribute substantially to an increase in morbidity due to their concentration, quantity, or physical, chemical, or infectious characteristics. According to the EPA, hazardous wastes "possess properties which make them dangerous or capable of having a harmful effect on human health or the environment". Large amounts of hazardous substance-containing effluent are discharged into the environment resulting from industrialization and urban development processes (Wiśniewska et al., 2017). They can increase the risk of motility because they are corrosive, flammable, or have a high affinity and readily react when exposed to other substances (Letcher and Slack, 2019; Muralikrishna and Manickam, 2017). Toxicity is the most concerning of these characteristics due to its impact on human beings and other living organisms. Hazardous pollutants sources include hormones, pesticides, antimicrobial agents, illicit drugs, pharmaceuticals and personal care products (Margot et al., 2015). The waste generated during the production of pharmaceuticals varies greatly in amount and type and is relatively more than the actual finished product. The term "pharmaceutical wastewater" primarily refers to effluents and wastes generated during pharmaceutical manufacturing. There can be anywhere from 200 to 30,000 kg of waste produced for each kilogram of active ingredient

produced (NRDC 2009; Lefebvre et al., 2014). The amount of wastewater produced by pharmaceutical manufacturing facilities grows as the industry expands. The current rate of improper disposal of unused medicines from hospitals and households is concerning (Santos et al., 2007, Tong et al., 2011, Vellinga et al., 2014). Pharmaceutical waste is broadly classified as: a) waste generated by pharmaceutical companies and effluents from treatment and recycling plants handling such wastes, and medical waste from hospitals and households, which significantly contaminates sewage systems. The latter is to blame for the presence of pharmaceutically active compounds (PhACs) in public sewers and, as a result, municipal wastewater treatment plants (Baumgarten et al., 2007; Pal, 2018). Analgesics, broncho spasmolytics, antibiotics, cosmetics, contraceptives, anti-depressive agents, non-steroid anti-inflammatory drugs (NSAIDs), lipid regulators, antiseptics, anti-rheumatic beta blockers, and diuretics have been discovered in the feed of municipal wastewater treatment plants as well as in the effluents of sewage-treatment plants to a scale of g/ml (Ahmed et al., 2017; Pal, 2018). Various treatment options are available for treating pharmaceutical wastewater, but due to the complex nature of the effluents, treatment can be challenging.

Gadipelly et al., (2014) and Zaied, et al., (2020) in their studies gave a comprehensive list of composition of the wastewater generated in pharmaceutical industries and active ingredients. Various treatment technologies exist and have been adopted for treatment of pharmaceutical wastewater as presented in Table 2. As a result of the complexities of industrial effluents, there is no one-size-fits-all method, and currently, no single method capable of adequate treatment is available. For example, despite the success of anaerobic digestion technologies in treating high-strength antibiotic wastewater with benefits such as biogas production and reduced waste sludge production (Ma et al., 2018), issues such as long start-up times, slow anaerobic microorganism growth rates, and poor biomass retention persist (Huang et al., 2018).

The investigation of the adsorption efficiency by Gao et al., (2012) of tetracycline by GO reveals that the removal of tetracycline is achieved majorly through a π-π and cation-π interactions with a maximum monolayer adsorption capability is 313 mg/g and it decreases with increase in the solution's pH or the sodium ions concentration. Moreira et al. (2020) demonstrated the simultaneous adsorption and degradation of norfloxacin (NOR) in an aqueous matrix by GO. The authors reported that the 8 layers GO was created through oxidation or exfoliation of the enlarged graphite using a modified Hummer's method. The removal capacity of the GO adsorbent was 374.9

±29.8 mg/g, with higher input from the NO-R in the zwitterionic form and removes about 94.8 %. The intra-particle diffusion process, as measured by Boyd's model and Fick's law, contributed more to the removal process and reaches equilibrium half hour after it began. Finally, the process underwent scale up in a single-stage batch adsorber with a 95% efficiency of NOR removal.

Rajabi et al. (2019) also reported the treatment of hazardous chemical and strong mutagen ethidium monoazide bromide (EMA) from aqueous solution using a GO adsorbent surface. The authors also reported on the investigation of variables such as solution temperature, contact time, ethidium monoazide bromide initial concentration, and pH affecting the process. EMA adsorption result on GO, the optimum time and pH, respectively, were 17 min and pH 10. The authors reported its maximum adsorptive efficiency of 76.92 mg/g at 303 K.

448 **Table 2: Pharmaceutical waste treatment**

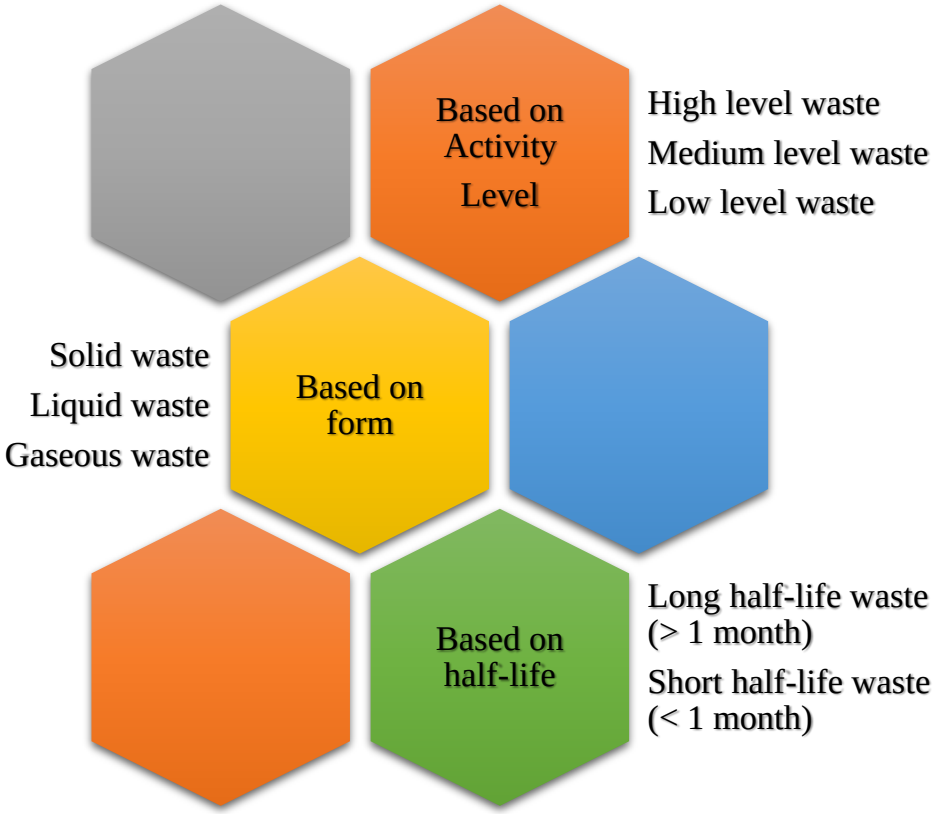
Treatment technology	Examples	Type	Sub type	Operation	Merits	Demerits	References
Biological treatment	PPCPs and Endocrine disruptors	Vermicomposting		Use of earthworms to convert organic materials (usually waste) into a humus-like material	Pharmaceutical wastes are broken down and converted to harmless or useful forms		Innemanová et al., (2022)
		Composting		sludge mixed with carbonaceous matter (e.g., sawdust, wood chips)	Reduce secondary pollution and treatment of sewage		Haiba, et al., (2013)
		anaerobic treatment			biogas production, less waste sludge production and cost effectiveness	Default start-up time is lengthy, slow-growth rates of anaerobic microorganisms	
		activated sludge			high volume load and fast reaction speed		
		Biological reactor	Membrane bioreactor		produce high quality effluent devoid of suspended solids		
			Sequencing bioreactor				
Physicochemical method	oxytetracycline, gentamicin and tetracycline	coagulation-flocculation		Agglomeration, uptake of pollutants and separation of products formed	Biodegradation performance of the wastewater is greatly enhanced. Reduction in the concentration of the pollutants	generation of secondary waste	
	doxycycline	Electrocoagulation			Efficient elimination of SS, oils, greases, color and metals	Flocs will need to be filtered, requires post treatment	
	PPCPs (100%)	membrane technology	membrane filtration	Nondestructive separation	Small space requirement, high	High operational cost, rapid	Wang, et al., (2018)

			efficiency even at high concentrations, no chemicals are used	membrane clogging
	microfiltration/ultrafiltration/nanofiltration			
	Reverse osmosis			
Adsorption		Surface chemistry and pore-size distribution	It allows for easy elimination of most micropollutants whilst averting byproducts formation.	Recycling and management of spent adsorbent waste
ion–exchange			No perforation of substances into the soft water	Initial cost of the selective resin, the acidity level in the water can be increased to allow sodium ions to enter the softened water, making the water unsafe to use.
chemical reduction				
Constructed wetlands			High removal efficiency of micropollutants from pharmaceutical wastewater, cost effective and low energy usage	

Advanced Oxidation Processes	Cetirizine	electrochemical processes	Electro-oxidation	Oxidizing agents	Good processing efficiency, easy to operate, and offers recyclability of useful materials,	Using AOPs solely to handle large amounts of wastewater is not cost-effective.	Agnihotri et al. (2018)
	sulfamethazine	Fenton process	Electro-chemical reduction Electro-fenton	Reactive species (OH^-, SO_4^{2-})	Organic matter is easily targeted and oxidized.	The technology is not mature for full scale and industrial use	Tang and Wang (2018)
	tetracycline hydrochloride	Photocatalysis	Fenton like Photo-fenton		remove harmful organic substances in wastewater		Lei, et al. (2018)
	N,N-dimethylacetamide	Ozonation//catalytic ozonation			increase the biodegradability of the pharmaceutical wastewater, Organic contaminants can be removed, disinfection and sterilization	Oxidative by-products are formed, Expensive to deploy	Peng, Yan, et al. (2018)

454 3.3 Radioactive Biowaste Treatment

455 Radionuclide application in medicine is a well-established field. When utilized appropriately in a
456 variety of medical applications for diagnostic, therapeutic, and research purposes, radioactive
457 materials have been found to be extremely effective (IAEA, 2000). Their usefulness, market
458 availability and reasonable price also make radioactive substances desirable. Handling these
459 materials has invariably led to the generation of biomedical radioactive waste in form of residues
460 and by-products. The amount and type of waste produced differ according to the size of the medical
461 application and the radionuclides used. Classification of radioactive waste can be made depending
462 on various attributes as shown **in** Fig. 4.



463

464 Fig.4. Various classifications of radioactive waste

465 With the exception of some medium-level waste, the majority of hospital radioactive waste is low-
466 level waste (low energy and emitters) with short half-lives. The nuclear industry and nuclear
467 reactors are typically associated with high-level waste (Khan et al., 2010). Different types of
468 radionuclides are utilized in hospitals and medical centers for "in vivo" and "in vitro" applications.
469 They have been implemented for diagnostics, research, and therapeutic uses. Radioactive waste

could be generated as solid or liquid wastes from radionuclide medical applications (Chartier, 2014). The major sources of liquid radioactive waste can be seen in Fig. 5**.** The radioactive waste management plan must be exhaustive and take into account all facets, from radionuclide procurement to the final release of waste packages from the facility for disposal/discharge. A good management plan should consider both original and secondary waste sources, the latter being from subsequent treatment and conditioning of the original. In any case that waste generation can be avoided or at least minimized, it should be implemented as the most preferable option. When waste prevention cannot be implemented, other approaches have been adopted. For instance, in some countries, diluting the overall radionuclide content of waste is permitted under certain conditions. Non-radioactive wastes are used to dilute low level radioactive waste in order to meet the regulatory specifications (IAEA, 2000).

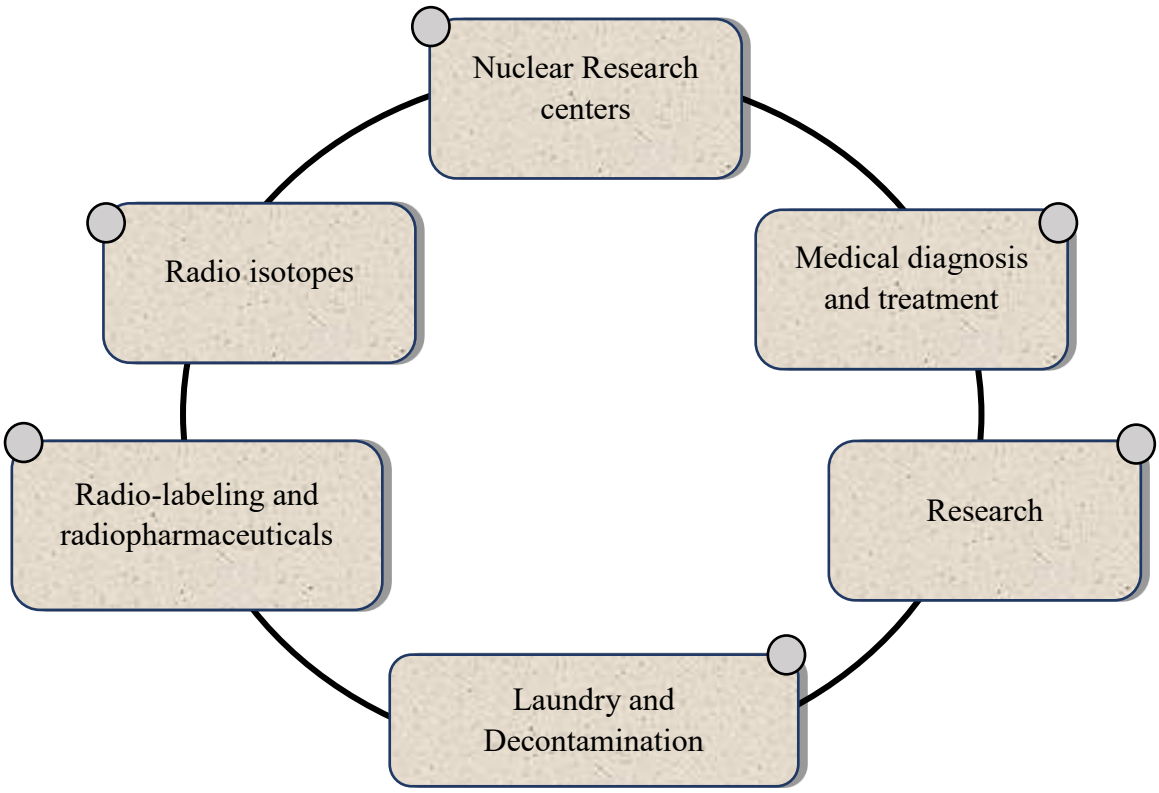


Fig.5. Sources of radioactive wastes

In order to ensure safe discharge into the environment, liquid radioactive waste must meet extremely stringent requirements concerning radioactive substance limits and other impurities. The treatment of liquid radioactive waste frequently involves the application of several steps such

as filtration, precipitation, sorption, chemical precipitation, sedimentation, flocculation, ion exchange (Figueiredo et al., 2018), evaporation, and/or membrane separation to meet the requirements for both the release of decontaminated effluents into the environment and the conditioning of waste concentrates for disposal (Zakrzewska-Trznadel, 2013; Lehto, 2019). Ren et al., (2008) performed experimental treatment on saline low-level radioactive waste containing plutonium (^{94}Pu) and Uranium (^{235}U). Flocculation was used for successful removal of ^{94}Pu and ^{235}U respectively under alkaline acidic conditions. A 95.5 % removal efficiency of ^{235}U was observed. Dulama et al., (2008) used membrane technology combined with inorganic sorbents for the treatment of radioactive liquid waste containing Cesium (^{137}Cs). The study found that using natural zeolite in the pre-treatment stage resulted in greater ^{137}Cs removal efficiencies, which were credited to the affinity of the materials for ^{137}Cs. Subsequently, various materials including Inorganic adsorbents have been successfully employed to mitigate radioactive waste as an alternative treatment technology. They possess high exchange capacity, possible selectivity, and specificity, and are resistant to radioactive radiation. Emerging processes bearing higher efficiency in recent times have been used in radioactive decontamination. Membrane technologies, particularly pressure-driven ones such as reverse osmosis, microfiltration, and ultrafiltration, play a large role in these processes. Membrane technologies outperform traditional processes in several ways, including lower energy consumption, no chemical addition, operation at low temperatures, and ease of scaling-up. Furthermore, a suitable combination of different processes can simultaneously remove radioactive, organic, and biological substances. These processes have been used successfully in the treatment of a variety radioactive effluents. Fouling, on the other hand, is a major issue in membrane processes and can be caused by inorganic, organic, or even biological substances. Membrane fouling reduces the flux that passes through the membrane, degrades permeate quality, reduces membrane life and raises operating costs. Membrane fouling can be reduced by using appropriate pretreatment operating parameters including composite membranes matrices by the inclusion of TiO_2, ZnO and graphene oxide nanomaterials with benefits such as thermal, physical and chemical stability. Other alternatives such as graphene oxide and mixed matrix membranes provide higher biofouling resistance, long-term stability and possible regeneration of membrane material.

4. Graphene-based nanocomposites

The performance of graphene adsorbents is mostly determined by their uniform dispersion in solution as well as their high sorption capacity to a variety of contaminants. Graphene often has a high affinity to aggregate or even roll to form graphite during liquid processing (Hosseini, H., et al., 2022). Aggregation can limit its adsorptive applicability by obstructing active sorption sites, limiting theoretical surface area, and impeding rapid mass transfer. Due to the electrostatic repulsion between them, GO has a low binding affinity to anionic dyes. Furthermore, due to its high solubility, GO cannot be regenerated easily from wastewater treatment, resulting in secondary pollution to the environment; hence, its application in pollutant treatment is limited (Chen et al., 2021). All of these aforementioned drawbacks can be overcome by functionalizing GO with various covalent or non-covalent dissimilar molecules, polymers, and nanoparticles, resulting in the development of composites, a class of multicomponent materials (Ali et al., 2021). The composite that results is more than just the sum of the separate components; it is a new substance with new functionalities and qualities. (Nagarajan et al., 2022). The synthesis method and surface area of various graphene-based nanocomposites reported from recent works is presented in Table 3 summarizes the recent works in the development of graphene composites materials. As a result of their enormous surface area, enhanced stability avoiding π- π stacking between, and numerous active sites for adsorption, graphene-based materials have attracted a lot of interest as appealing candidate for adsorptive removal of contaminants from water. (Yan and Li, 2022). The underlying adsorption principles are used to design graphene-based adsorbents for target pollutants. Better understanding of graphene-based adsorption performance and how it relates to the interactions between pollutants and adsorbents is crucial for the future development of graphene-based functional materials and their practical applications. (Mahmoodi et al., 2019). Nagarajan et al., (2022) reported the fabrication of magnesium nanocomposites decorated with multilayer graphene (MG) and its application in pollutant treatment in a recent study. The BET surface area of the developed graphene-based nanocomposite was found to be 1480 m^2/g. The synthesis of Polypyrrole functionalized Cobalt oxide Graphene (COPYGO) nanocomposite via hydrothermal method was explored by Anuma et al., (2021). The authors reported the BET surface area of 133 m^2/g. Verma et al., (2022) functionalized graphene oxide-chitosan with EDTA for inorganic and organic pollutants treatment. The BET surface area of 1.326 m^2/g was reported by the authors. The fabrication of graphene hydrogel decorated on nickel with BET surface area of 67.84 m^2/g was

explored by Ebratkhahan et al., (2022). Chen et al., (2021) also reported the BET surface area 41.54 m^2/g for the fabrication of carbon layer encapsulated Fe_3O_4 /graphene oxide nanocomposites rich in amino and thiol groups (Fe_3O_4 @C /GO).

Table 3. Graphene-based nanocomposites synthesis and their respective surface areas

Graphene-based nanocomposite	Preparation method	BET surface area (m^2/g)	References
MG	Simple combustion process	1480	Nagarajan et al., (2022)
COPYGO	Hydrothermal	133	Anuma et al., (2021)
GO-EDTA-CS	modified covalent binding and electrostatic interaction process	1.326	Verma et al., (2022)
GH-Ni	polyol and hydrothermal	67.84	Ebratkhahan et al., (2022)
Fe_3O_4 @C /GO	Solvothermal	41.54	Chen et al., (2021)
Gr_5-SBA/TiO_2 NCs	co-condensation hydrothermal	340.45	Ali et al., (2021)
ZIF-8/$CoFe_2O_4$/GO	Ultrasound-assisted	2490	Mahmoodi et al., (2019)
Fe_3O_4/porous graphene nanocomposites.	Hydrothermal	410	Bharath et al., (2017)
CMC-PAA-GO	Freeze-drying	42	Hosseini et al., (2022)
Fe_3O_4/G-AC	catalytic graphitization	485.8	

5. Biomedical treatment using graphene-based nanocomposites

Graphene is fundamentally a monatomic graphite layer, a mineral-rich allotrope of carbon made up of tightly bonded carbon atoms organized in a hexagonal lattice. As a result of its sp2 hybridization and extremely thin atomic thickness of 0.345 nm, graphene is a very distinct material (Reddy et al., 2019). However, its hydrophobic nature which makes it insoluble in hydrophilic solvents like water limits its application in water purification. In order to overcome this limitation, the hydrophobic nature must be compromised. To improve its affinity to aqueous solution, graphene's have been modified by adding functional groups on its surface through chemical modification, covalent, or noncovalent functionalization giving rise to the graphene-based nanomaterials. Owing to their attractive properties which include water-solubility, low toxicity, very good water dispersibility, antibacterial activity, high adsorption rate, graphene-based nanomaterials have more advantages over other materials such as high adsorption rate, high dispersion rate and antibacterial activity which makes them a better choice for biomedical

wastewater treatment (Balasubramani et al., 2020). Recently, graphene-based materials have received a lot of attention as potential adsorbents for wastewater treatment. In wastewater treatment, graphene is an intriguing carbon material having distinct advantages over other adsorbents such as activated carbon, carbon nanotubes, chitosan, clay, and zeolite. Graphene is an appealing material for use in wastewater treatment considering its increased surface area for adsorption of biomedical contaminant species, as well as the possible chemical modifications and composite fabrication (Yu et al., 2016; Jeyaseelan et al., 2021). As earlier stated, the modifiable chemical properties of graphene alongside its large surface area, highly delocalized π-electrons positions them as very captivating and auspicious for usage to adsorb pollutants in wastewater and address environmental sustainability concerns. However, vehement inter-planar interactions make graphene nano-layers jointly incline and also recombine to produce graphite. As a result of tough electrostatic repulsion between graphene oxide and negatively charged compounds, the binding affinity between them is weak.

Notwithstanding, the possibility of graphene alongside graphene oxide not composing and coming off decontaminated effluents leads to serious re-contamination. Overcoming these disadvantages is possible by functionalizing covalently or non-covalently using different molecules and other nanoparticles, through which, nanocomposites - multi-component material groups are produced, where one phase is dispersed into another in the nanometric range (Ali, 2019). Several researchers have shown the high adsorption capacity of graphene-based materials and most studies consider solution pH, ionic strength, and temperature as essential parameters in biomedical pollutants treatment, in addition to the adsorbent's intrinsic properties (Ersan et al., 2017). Adsorption interactions are non-covalent interactions that occur between pollutants and graphene-based materials as presented in Fig. 6. However, the true nature of such interactions such as electrostatic, hydrogen bonds, hydrophobic and Van der Waals interactions as well as their relative contributions, are hotly debated (Kern et al., 2022). Their surface chemistry heavily influences the adsorption and photocatalytic properties of graphene-based materials. Oxygen-containing functional groups on the surface of GO have two opposing effects on adsorption capacity. Adsorption can be boosted by increasing the water solubility on the surface of a surface charge; however, there is a reduction in adsorption sites by the water clusters produced on the surface. The oxygen concentration of graphene oxide, on the other hand, increases the adsorption of

contaminants such as amino acids and hydroxyl groups via strong hydrogen or Lewis' interactions (Priyadharshini et al., 2022).

Gao et al., (2012) developed the GO as a potential adsorbent for the removal of Significant concerns tetracycline antibiotics from aqueous environment. The authors observed that the tetracycline was deposited strongly via π–π interaction and cation–π bonding on the surface GO. The adsorption equilibrium data was found to fits well the Langmuir and Temkin isotherm model with theoretical maximum of adsorption capacity 313 mg/g. The adsorption kinetics was well described by pseudo-second-order model.

Komal et al., (2022) conducted an extensive study to evaluate the effect of percentage load of functionalized graphene oxide on the development of various forms of modified GO supported with functionalized cellulose nanofibers (CNF) obtained from excess biomass for the treatment of toxic drug species from aqueous environments. The authors assessed the adsorptive performance of the developed nanohybrids for the treatment of ciprofloxacin and ofloxacin and optimized their performance varying adsorbent loading, pH, and initial drug concentration. Furthermore, different kinetic and isotherm adsorption models were studied to investigate adsorbent properties and the adsorption process. The adsorptive capability of functionalized CNF was significantly improved by its easy aggregation with functionalized graphene oxide. The results of the experiments revealed that a 20 wt% loading of carboxylated GO within the perforated surface of esterified CNFs showed excellent adsorption efficiency, with peak at 45.04 mg/g for ciprofloxacin and 85.30 mg/g for ofloxacin uptake. The interaction of electronegative functional groups and deficient structure found on CIP with aromatic structure found within GO basal planes and functionalized GO edges can explain the underlying chemisorption mechanism. Hydrogen bonding is also an influential feature whereby CIP molecules adhere to the nanocomposite surface because both the adsorbent and adsorbate moieties contain a lot of oxygen and hydrogen rich functional groups. The possibility of regeneration and reusability of nanocomposites opens up enormous possibilities for low-cost, long-term sorbent material development for pharmaceutical pollution management.

Januário et al., (2022) recently reported on the use of GO functionalized activated carbon (GAC-GO) for the efficient uptake of pharmaceuticals for COVID-19 treatment from water. This study aimed to remove water contaminated with chloroquine and dipyrone using batch adsorption processes. In this study, the authors discovered that the equilibrium time for chloroquine and

dipyrone adsorption was 18 and 12 h, respectively. The adsorption of chloroquine and dipyrone onto GAC-GO fits the Langmuir model best and follows pseudo-second order. Thermodynamic studies revealed that the process is endothermic, with adsorption capacity of 37.65 and 62.43 mg/g at its peak at 318 K, respectively. The main mechanism of the underlying adsorption process was attributed to hydrogen bonds and π-interactions between chloroquine and GAC-GO.

Mortazavi et al. (2019) reported that GO was simultaneously subjected to thermal reduction and chemical bonding on the surface of amino-functionalized sand particles (AFSPs) and was employed to adsorb naphthalene and acenaphthene from aquatic environments. The experimental data were fitted to the Langmuir, Redlich-Peterson, and Dubinin-Radushkevich models for naphthalene adsorption, and the Redlich-Peterson and Freundlich models for acenaphthene adsorption, according to the equilibrium results analysis. The kinetic studies reveal both adsorbate's adsorption process proceeds the pseudo-second-order and intra-particle diffusion models. Naphthalene and acenaphthene had maximum adsorption capacities of 7.473 and 18.152 mg/g, respectively. Adsorption mechanisms in this study includes π–π stacking and hydrophobic interactions: during thermal reduction, GO lose most of its functional groups, and amino-functionalized sand particles were coated with rGO as a hydrophobic layer which promotes hydrophobic interaction between rGO and the adsorbates (naphthalene and acenaphthene). The - stacking mechanism is another adsorption mechanism that could be responsible for adsorption capabilities.

Zhang et al., (2022a) outstanding polyvinylidene fluoride (PVDF)-PB-graphene oxide (GO) adjusted membrane was synthesized through phase inversion for a small amount radio-nuclide cesium (^{137}Cs) adsorption from wastewater. The authors reported that integration of GO increased PB diffusivity, and the PVDF-PB-GO membrane displayed the largest Cs^+ uptake effectiveness of 99.6 %. Moreover, the membrane displayed conspicuous selectivity and reusability towards small quantity of radioactive cesium, even in the presence of extreme co-existing ions and in real water, which showed convincingly that the membrane has potential for usage. Two pathways were suggested to account for Cs^+ adsorption behavior unto modified PVDF-PB-GO membrane. Firstly, the XPS survey revealed that the N-Fe binding of PB was replaced by $C{\equiv}N\cdots Cs^+$ with the elimination of Fe $2p^3$ after adsorption suggesting that $Fe(CN)_6^{4-}$ defect sites could as well be active adsorption sites. Furthermore, the adsorption of Cs^+ can also be attributed to oxygen containing

surface functional groups (O—H group and C==O stretch) on the surface of GO as evidenced by FT-IR spectra analysis.

Ma et al., (2017) investigated the utilization of GO membrane in the adsorption of Cs(I) and Sr(II) from wastewater. The authors observed that Cs(I) and Sr(II) ions diffused quickly through graphene oxide membranes, but the lanthanide ions and actinide ions are slower, making them to separate based on the variation in hydrated ionic radii. Furthermore, the initial metallic ion concentrations and acidity in the solution of the feed affected ion transport through the graphene oxide membranes, larger concentrations of initial metallic ions and acidity of the feed solution favored Cs(I) and Sr (II) adsorption.

In another recent study by Yang et al., (2021a), the sorption of radioactive waste U(VI) onto a synthesized novel magnetic composite graphene oxide/Fe_3O_4/glucose-COOH (GO/Fe_3O_4/GC) was investigated. At optimum adsorption conditions; an initial concentration of 10 mgL^{-1}, 5.0 pH value, and sorbent dosage of 0.15 g/L, the maximum adsorption capacity was observed to be (390.70 mg/g) at 30 mins of contact time. The observable higher U(VI) uptake and faster adsorption rate when compared to previously reported studies was credited to abundant presence of GO showing its effectiveness as an absorbent and potential for industrial use. Adsorption behavior could be explained by the Dubinin–Radushkevich (D–R) model which fitted well with the equilibrium data and showed a physical adsorption process taking place ($E < 8$ $kjmol^{-1}$). While the best fit for the adsorption kinetic parameter is pseudo-second order, indicating a high level of complexation between U(VI) ions and organic functional groups observed on the as manufactured nanocomposite.

ALOthman et al., (2022) fabricated γ-Cyclodextrin-graphene oxide nanocomposite for the treatment of tetracycline and chlortetracycline antibiotics removal from aqueous environment. The authors reported that the adsorption optimum conditions under studied were concentration of 400 mg/L, 30 min adsorbent time, pH 8.0, adsorbent dose 1.0 g/L and temperature of 278 K. The adsorption of tetracycline and chlortetracycline was described best by the Freundlich model suggesting a multilayer adsorption. The maximum percentage treatment of tetracycline and chlortetracycline were found to be 91.25 and 93.75 % respectively. The adsorption process was revealed to follow pseudo-second kinetic order reaction and liquid film diffusion kinetic model.

The thermodynamics study revealed degree of freedom increase, exothermic and spontaneous in nature. The hydrogen bonding and π-π interactions were adsorption mechanism of adsorption.

The fabrication of copper nanoparticles immobilized-*β*-cyclodextrin modified reduced graphene oxide (Cu/β-CD/rGO) were developed successfully as an effective extractor of tetracycline (TC), oxytetracycline (OTC) and doxycycline (DC) antibiotics from various aqueous environment was explored by Yakout et al., (2021). The authors revealed that TCs are deposited strongly Cu/β-CD/rGO nanocomposite matrix via surface complexation with the Cu-nanoparticles besides the formation of inclusion complexes with β-cyclodextrin and π-π interaction of reduced graphene oxide. The maximum adsorption capacity of Cu/β-CD/rGO evaluated from the Langmuir isotherm model was found 403.2 mg/g, 476.2 mg/g and 434.8 mg/g for TC, OTC and DC respectively. It was concluded that the prepared novel nanocomposite demonstrated a quick and highly effective treatment performance for the antibiotic pollutant treatment.

Yang et al., (2022b) reported the synthesis of graphene oxide modified κ-carrageenan/sodium alginate (GO-κ-car/SA) gel for the removal of Ciprofloxacin (CIP) and Ofloxacin (OFL). It was revealed by the authors that GO nanosheets addition improves the mechanical strength and anti-swelling property of the double-network hydrogel, making it possible for the application in the fixed-bed column system. The maximum adsorption capacity calculated for CIP and OFL adsorption onto GO-κ-car/SA gel were 272.18 and 197.39 mg/g. The authors also reported that the GO-κ-car/SA gel was observed always to be negatively charged, suggesting that adsorption capacity of the gel is better in an acidic environment.

Recently, Andrade et al., (2022) reported the preparation of graphene oxide (GO) anchored on iron oxide nanoparticles (αγ-Fe_2O_3) and cobalt oxide (Co_3O_4) for the removal of caffeine in a batch adsorption The GO#αγ-$Fe_2O_3Co_3O_4$ adsorbent was reported to have demonstrated about 80v% removal coupled maximum adsorption capacity of 28.94 mg/g. The adsorption kinetics as well as the adsorption GO#αγ-$Fe_2O_3Co_3O_4$ was reported to follow a pseudo-second order kinetics and better fitted to the Langmuir and Temkin models isotherms adsorption data. The thermodynamic variables studied revealed that the adsorption process was exothermic, spontaneous and favorable.

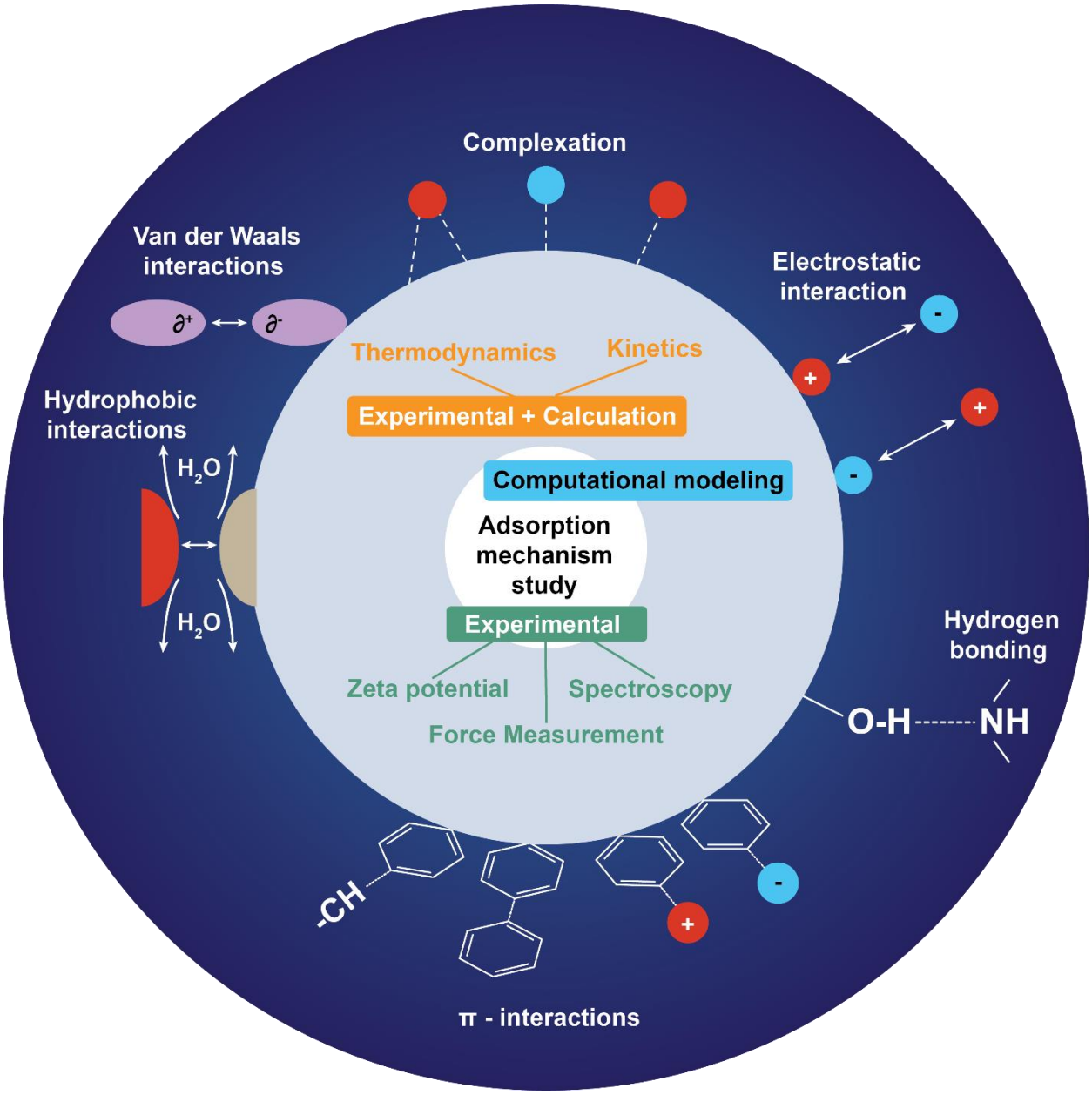


Fig. 6. Insights into possible adsorption mechanism of biomedical waste onto graphene-based materials (Source: Wang et al., 2021a)

6. Adsorption isotherm and kinetic studies

Studies of isotherm and kinetics of adsorption experiment is a way of understanding probable mechanisms as well as pathways associated with the process. Generally, the adsorption isotherms refer to the quantity of pollutant adsorbed with the pollutant's concentration in the substrate at equilibrium. It is also needed to evaluate the adsorbent's efficiency for removing contaminants and investigate the surface properties (Xing et al., 2015). An earlier study of adsorption isotherms

shows the most frequently used isotherms are Freundlich and Langmuir isotherms as shown in Table 4 (Wang et al., 2017). The availability of several proved isotherms established on various assumptions and instances, the closest to the real case is fitted to the experimental data. Consequently, the study of the isotherms statistically is done to detect the models that depict and best fits the process of contaminants removal from effluents after analysis by several categories of nanoadsorbents (Ahmed et al., 2020).

Table 4. The most common isotherm model equations in adsorption

Models	Equation	Plot	Parameters	References
Langmuir	$\frac{C_e}{q_e} = \frac{1}{q_m K_L} + \frac{C_e}{q_m}$	$\frac{C_e}{q_e} vs\ c_e$	q_m, K_L	Langmuir, (1916)
Freundlich	$\log q_e = \log K_F + \frac{1}{n} \log C_e$	$\log q_e\ vs \log C_e$	$K_F, \frac{1}{n}$	Freundlich, (1906)

where q_m represents peak adsorption capability of metal ions (mg/g); K_L, the Langmuir isotherm constant (L/g); C_0, and C_e are the initial concentration and concentration at equilibrium respectively (mg/L), k_f represents Freundlich constant in relation to adsorption capability, and n is the adsorption intensity. The Langmuir isotherm assumes that antibiotic molecules removal takes place on a uniform surface by monolayer adsorption with uniform binding sites, similar energy, and no movement between adsorbed species (Li et al., 2011). In contrast, Freundlich isotherm is an empirical model depicting heterogeneous surfaces (Zanin et al., 2017). The treatment process is favorable whenever 1/n in the Freundlich model equation is below 1 (Park et al., 2016). In the interpretation of adsorption, there exist differences in the effectiveness of Langmuir and Freundlich models. However, some of these models' variables such as excessive adsorption capacity (Langmuir) and constant linked to the distribution coefficient (Freundlich), have broad application in the characterization of the adsorption capacity for various species.

Graphene and its derivatives have risen as a novel material for usage as efficacious material to be applied in wastewater treatment. Due to their exceptional properties such as large number of functional groups, high surface area, and exceptional charge carrier mobility, Gr-based materials are exploited as sorbents for effluent decontamination.

Wu et al. (2013) reported the removal of doxorubicin hydrochloride from an aqueous solution using GO. The authors found that the maximum adsorption capacity was 1428.57 mg/ and concluded that the Langmuir model fit better experimental data than the Freundlich model.

Sulfamethoxazole (SMX) uptake by graphene oxide was studied by Nam et al. (2015). It was discovered that Freundlich model had a better fit for the adsorption isotherm data than Langmuir model based on the correlation coefficients. In the study of TC uptake using Fe_3O_4@SiO_2-chitosan/GO (MSCG), the isotherms of adsorption were simulated with both Freundlich and Langmuir equations. The authors revealed the appropriateness of Freundlich model more than Langmuir for Tetracycline removal.

The removal of oxytetracycline (OTC) and TC by Fe_3O_4@G was investigated by Zhang et al., (2017). The result obtained showed higher correlation coefficient with the Langmuir model than Freundlich model: Langmuir: R^2 =0.990 and 0.924, Freundlich: =0.986 and 0.921 for TC and OTC respectively, suggesting a monolayer adsorption and uniform distribution of adsorption site.

Wang et al., (2020) investigated the effective adsorption of TC- hydrochloride antibiotics with synthesized Zr-based MOF composite UiO-66-$(COOH)_2$/GO. The result obtained for R^2 when compared showed that the experimental data best fits the Langmuir model ($0.9935 < R^2 < 0.9967$) than Freundlich model ($0.9401 < R^2 < 0.9872$), revealing mono-layer mechanism of interaction and uniform TC uptake on the MOF.

GO and GO-CMC (carboxymethylcellulose) nanomaterials were synthesized in films by Juengchareonpoon et al., (2021). It was also restructured with citric acid crosslinks for adsorption of antibiotics. The obtained results revealed maximum adsorption capability of 370.93, 256.68 and 102.05 mg/g for trimethoprim, oxolinic acid and oxytetracycline respectively at 30 ^{O}C.

Suksompong et al, (2021) studied the possibility of adsorbing iodine-131 from a hydrous solution using GO/Chitosan sponges. The adsorption efficiency was studied making use of stable isotopes and further studied using iodine-131 radioisotopes for confirmation of results. The experimental data fitted well with the Langmuir model. The value of R_L (separated factor) obtained was between 0-1 substantiating the favourability of the adsorption of iodide using GO/Chitosan sponges with maximum adsorptive capability of 0.263 MBq/mg.

ALOthman et al., (2022) also synthesized γ-Cyclodextrin-GO nanocomposite for the uptake of TC and Chloro-TC antibiotics from water. The authors revealed that the sorption followed Langmuir model. The highest percentage removal of TC and Chloro-TC were 91.25 and 93.75 % respectively, at different pH values.

Feng et al., (2022) developed novel GO/COF-300/PPy sorbent via hydrothermal method to adsorb indomethacin (IDM) and diclofenac (DCF) from water. The results reveal the adsorption capability and uptake efficacy of indomethacin and diclofenac by GO/2COF-300/4PPy is high at 99% for indomethacin and 97 % for diclofenac (115 mg/g and 138 mg/g respectively). The authors also revealed that adsorption of indomethacin and diclofenac onto GO/2COF-300/4PPy conformed to the Langmuir isothermal model.

Yang et al., (2022c) studied the removal of enrofloxacin (ENF) onto GO. The authors concluded that the Langmuir-Freundlich model gave the best fit of adsorption process with an adsorption capacity of 45.035 mg/g.

Adsorption kinetic models are highly crucial for predicting optimal conditions especially for batch adsorption processes (Kyzas et al., 2018). Kinetic modeling gives robust interpretation concerning adsorption forces/interactions which reveals the entire adsorption mechanism and potential rate-controlling steps like mass transport or processes involving chemical reaction. Some widely explored models include Pseudo-first and pseudo-second order, Elovich equation and intraparticle diffusion (Awad et al., 2020). But recently the pseudo-first and the pseudo-second order are the most explored kinetic model equations. The linear form equation of the models mentioned above is depicted in Table 5. The pseudo-first order kinetic model physisorption as the basis of adsorption process, occurring without any chemical bonding and only through weak Van der Waals forces. The adsorption process is easily reversible which allows for a near effortless regeneration. According to the pseudo-second order, two reactions occur either simultaneously or sequentially. Given that the initial reaction is quick, it reaches equilibrium quickly. Meanwhile, the second reaction proceeds steadily and takes longer to arrive at equilibrium (Wang et al., 2015). Adsorption occurs via chemisorption, as indicated by the pseudo-second order. It is concluded that bonding occurs as a result of electronic sharing, and that the transfer between adsorbents and adsorbate is

relatively stronger than the physisorption pathway from pseudo-first order kinetics (Ahmad et al., 2020).

Table 5. The most common kinetic model equations in adsorption

Kinetic models	Linear form	Plot	Parameters	Reference
Pseudo-first-order	$\log\ (q_e - q_t) = \log q_e - \frac{k_1 t}{2.303}$	$\log\ (q_e - q_t)$ vs t	$q_{e,cal}, k_1$	Lagergren and Svenska, 1898
Pseudo-second- order	$\frac{t}{q_t} = \frac{t}{q_e} + \frac{1}{k_2 q_e^2}$	$\frac{t}{q_t}$ vs t	$q_{e,cal}, k_2$	Ho and McKay, 1999

where k_1 is the pseudo-first-rate constant (min^{-1}), k_2 is the pseudo-second order rate constant (g/mgmin), $q_e\ and q_t$ are the adsorption capacity at equilibrium and time, t (mg/g).

Understanding the kinetics of antibiotic adsorption on graphene graphene-based nanomaterials is essential to the adsorption mechanism and spent graphene/graphene-based nanomaterials, which is closely related to the diffusive state of graphene materials. Adsorption of antibiotics by graphene oxide with good diffusivity is fast. GO with good dispersibility can adsorb antibiotics quickly, but Gr and reduced graphene oxide (RGO) with low diffusive need more time to reach equilibrium (Li et al., 2018).

Zhu et al. (2015) reported that Gr exhibited swift adsorption capability and attained equilibrium in 3 min, and the removal process fitted well into the pseudo-second-order kinetic model compared to the pseudo-first-order model.

Song et al. (2016) discovered that the pseudo-second-order kinetic model better fitted the kinetics of TC and sulfamethazine removal by reducing graphene oxides than the pseudo-first-order model.

Wang et al. (2016) reported a similar result using MCGO to remove CIP. These facts suggest antibiotics removal by graphene/GBNPs is mainly controlled by chemical adsorption through the exchange or pairing of electrons between adsorbates.

Hiew et al., (2019) investigated removal of diclofenac using graphene oxide (GO). The authors reported PSO model as the optimal representation of the kinetic of diclofenac adsorption.

In another study, Ninwiwek et al., (2019) prepared mesoporous silica-magnetic graphene-oxide nanocomposite material (mGO-Si) for the uptake of sulfamethoxazole (SMX). The results shows the mGO-Si removed the sulfamethoxazole molecules more efficiently than the pristine magnetic-GO with the Kinetic data exhibiting good correlation based on the PSO model.

Radmehr et al., (2021) displayed the production and efficient deployment of renewable sorbents based on GO (i.e., NiZrAl-layered double hydroxide-graphene oxide-chitosan (NiZrAl-LDH-GO-CS NC)) for Nalidixic acid uptake. The kinetics of the Nalidixic acid being adsorbed on LDH-GO-CS was examined by the authors using PFO kinetic model, the pseudo-PSO, IPD and Elovich mechanism and discovered the R^2 values are positioned between 0.9884–0.9966 giving a well fitted Nalidixic acid removal by LDH-GO-CS NC as shown by the pseudo second order model.

Zou et al., (2021) reported the one-pot fabrication of -Fe_2O_3 nanoparticles growth on RGO for the adsorptive uptake of chlortetracycline, tetracycline, and oxytetracycline. The authors reported that the adsorption of chlortetracycline, tetracycline, and oxytetracycline onto -Fe_2O_3 @RGO nanocomposites take 20 min and is highly pH-dependent because of the enhanced repulsive interaction at high and low pH, and that the adsorptions fit well the PSO equations.

Jaswal et al., (2021) also reported the utilization of rGO-MoS_2heterostructure for the treatment of ofloxacin from the aqueous phase. It was found from the result that the adsorption of ofloxacin onto rGO-MoS_2 followed pseudo-second order kinetics.

7. Photocatalytic degradation of biomedical waste

Several chemical treatment methods such as ozonation, chlorination, and Fenton's oxidation have undergone developments for removing antibiotic remains from wastewater. However, difficult or extensively prolonged process in obtaining total decomposition and possible destruction of desirable organisms because of their low selectivity leading to undesirable losses are major drawbacks to these methods (Yang et al., 2021b). In addition to the above, the process incurs high economic capital and operational cost. Although integration of physical processes substantially reduces the noxiousness of water containing antibiotics after treatment, it is a rather knotty and expensive process (Homem and Santos, 2011). Sequel to adsorption, active groups such as -OH, -O_2 present in sunlight, visible light or UV light released by photocatalysts are used to disintegrate

antibiotics into unharmful quantities efficiently. Therefore, photocatalytic decomposition is one of the high-ranking processes for removing antibiotic contaminants from the environment due to its high efficiency and sustainability (Saher et al., 2020). As a result of its exceptional advantages such as its powerful redox potential, no adsorption engorgement, the possibility of totally degrading organic contaminant into unharmful inorganic matter (e.g. CO_2 and H_2O), inexpensiveness, mild reaction conditions (close to room temperature and atmospheric pressure), extraction of oxygen in air for the production of highly potent oxidants and solar radiation energy; photocatalysis possesses extensive prospect of application in environmental reclamation (Elmolla and Chaudhuri, 2010). Therefore, photocatalysis has progressively attracted global interest and broad application in novel energy extraction and techniques for environmental control. The fundamental principle of Photodegradation is the excitement and movement of electrons from their valance band into the conduction band after exposure to radiation with energy higher than its optical band gap which produces equal quantity of positively charged holes in the valance band (Xu et al., 2019). When the potential of the valence band vs normal hydrogen electrode (NHE) exhibits higher positivity than H_2O/**.**OH (+272 V vs NHE) or, OH^-/**.**OH (+189 V vs NHE) and the potential of conduction band vs NHE is more negative than O_2/**.**O_2^-(−0.33 V vs NHE), the semiconductor will be able to generate **.**OH and**.**O_2^-. Thereafter, separation and migration to the semiconductors surface of the photoinduced electrons and holes occurs and redox reactions will take place at the reactive site on the semiconductor surface. The mechanism of semiconductor photocatalysis reaction (Fig. 7) is given by the equations (Zhao et al., 2018; Yang et al., 2021b).

$$Semiconductor + Light\ Energy\ (\lambda \geq E_g) \rightarrow Semiconductor(e_{cb}^- + h_{vb}^+) \quad (1)$$

$$h_{vb}^+ + H_2O \rightarrow H^+ + \text{.OH}\ (H_2O/.\text{OH}| + 2.72\text{v vs NHE}) \quad (2)$$

$$h_{vb}^+ + OH^- \rightarrow \text{.OH}\ (OH^-/.\text{OH}| + 1.89\text{V vs NHE}) \quad (3)$$

$$e_{cb}^- + O_2 \rightarrow \text{.}O_2^-(O_2/.\boldsymbol{O_2^-}| - 0.33\text{ V vs NHE}) \quad (4)$$

$$Pollutant + Active\ species\ (h_{vb}^+,\ e_{cb}^-, \text{.OH}, \text{.}O_2^-) \rightarrow Degradation\ products \quad (5)$$

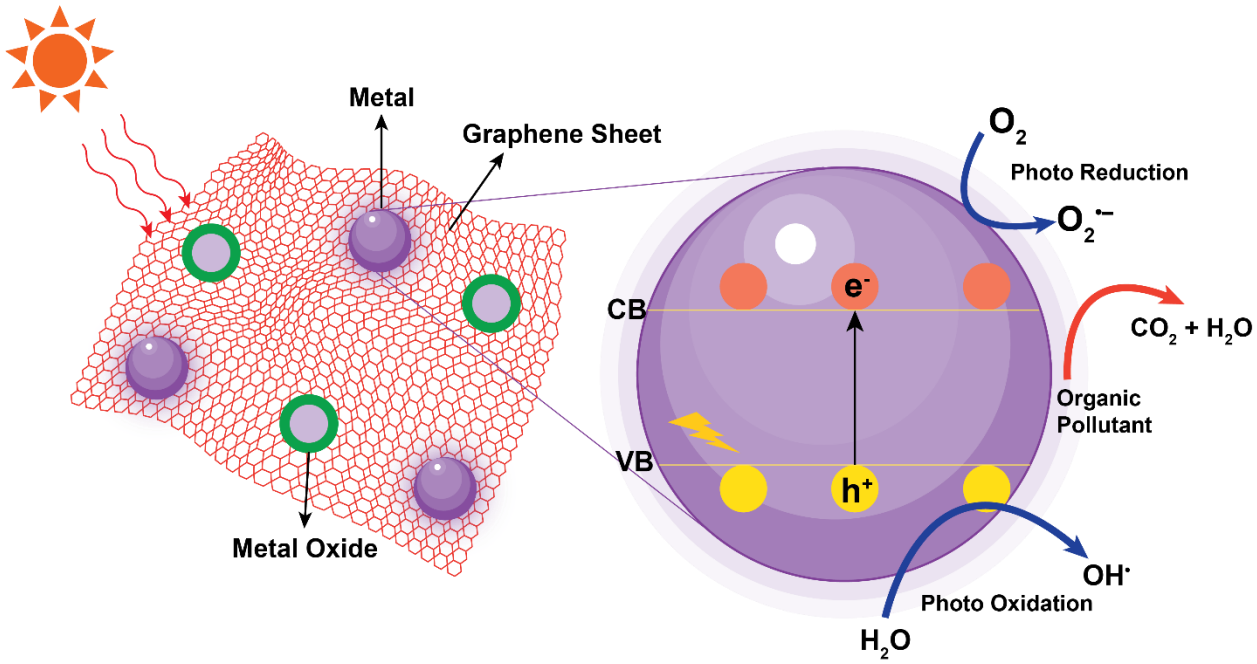


Fig. 7. Graphical illustration of photocatalytic reaction mechanism (Source: Ramalingam, et al., 2022)

High surface area for homogeneous diffusion, thin band gap vitality alongside unique electroconductivity in reposition and swift electron transport and minimal expenditure for large scale production makes graphene a prospective photocatalyst and has been extensively used for photocatalytic decomposition of antibiotic pollutant in water (Li et al., 2019). Nonetheless, catalytic activities are easily lost by graphene planes during its self-accumulation process (Julkapli and Bagheri, 2015) and research reveals the inability of GO, a significant component of graphene-based nanomaterials to function under visible light as a result of low (1.79 eV) band gap (Anirudhan 2017). This necessitates the combination of graphene with different photocatalysts to produce new graphene-based photocatalysts to overcome these disadvantages and enhance the catalytic operation of antibiotics. Recently, several steps have been taken to manufacture and produce graphene-based photocatalyst to enhance their capability to decompose antibiotic pollutants. Examples are single-semiconductor, coupled semiconductor, metal-coated single semiconductor, and metal-coated coupled-semiconductor. Single-semiconductors include metallic compounds and organometallic model such as Titanium oxide, Bi-based oxides, Zinc oxide, silver tetraoxophosphate and many more. they have been used to photocatalytically decompose organic contaminants. The metal-based hybrid nanocomposites material is redox capable and has a high charge separation efficiency. All of these factors are critical for the efficient photocatalytic

breakdown of organic contaminants. Figure 4 depicts the photocatalytic mechanism of a metal/metal oxide decorated graphene sheet for organic pollutant degradation. Mohamed et al., (2021) found that the multifunctional effects of Ag, CA, and GO on the structural characteristics of the graphene-based composite increased the photocatalytic activity of Ag-CdSe/GO/CA nanocomposites. According to the authors, GO acts as an electron acceptor, increasing the effectiveness of removing photo-generated carriers as well as the combined composite carrier.

Perera et al. (2012) created TiO2 nanotube/reduced graphene oxide composites using an alkaline hydrothermal technique. The photocatalytic activity of the composites was shown to be highly influenced by the rGO/TiO_2 ratio. Due to its high surface area and excellent electron/hole separation, the composite with 10% rGO had the highest photocatalytic activity, with a threefold improvement in photocatalytic efficiency over pure TiO2 nanotubes under UV and visible light.

Pan et al. (2012) employed the application of hydrothermal method to fabricate GO/TiO_2 nanowires and nanoparticles. TiO_2 nanowires disperse more uniformly on graphene with less agglomeration than TiO_2 nanoparticles, resulting in more direct contact between TiO_2 and graphene and thus enhanced electron-hole pair separation and transportation. As a result, GO/TiO_2 nanowires outperform GO/TiO_2 nanoparticles, pure TiO_2 nanowires, and TiO_2 nanoparticles in terms of relative photocatalytic activity.

The combination of graphene materials with coupled-semiconductors have become a research area of focus because it usually possesses extensive benefits of improving the disintegration of electron-hole pairs and retaining oxidation and reduction at two separate sites for reaction (Tang et al., 2015). Composite photocatalysts NeZnO/ CdS/GO was produced via a simplified hydrothermal process by Huo et al., (2016). The composite showed significant photocatalytic activities. Preparation of hetero-junction photocatalyst (Ag_3PO_4/$BiVO_4$/RGO) was a success through a simplified in-situ deposition process. Tayel et al (2018) discovered that coating TiO_2 with graphene oxide increased the TiO_2 catalytic activity by a factor of 1.2. The primary photocatalytic activity of TiO_2 resulted from the electron acceptance and GO transport (Zhang et al., 2020). The electrons accepted by GO were produced on the TiO_2 surface in the presence of light, which reduces electron-hole recombination and increases the production of active holes (Ajala et al., 2022). Another reason for the increased titanium oxide photocatalytic activity was the reduction in the

width of the TiO_2 band gap caused by the GO addition. This band gap narrowing allows the photocatalyst to produce radicals at elongated wavelengths. Several researchers have recently considered integrating two or more metallic oxides with GO as a potential method for increasing catalytically enhanced activity when organic pollutant begin to degrade.

Xu et al., (2020) investigated the photocatalytic degradation activities of ciprofloxacin (CIP), norfloxacin (NOR) and tetracycline (TC) over a series of rGO/$Bi_4O_5Br_2$. The authors revealed from the results obtained that photodegradation of these target antibiotics almost never be possible without adding any photocatalysts. The photodegradation of these antibiotics was successfully commenced by using $Bi_4O_5Br_2$ nanosheets and rGO/$Bi_4O_5Br_2$ nanocomposites as photocatalysts. As expected, the degradation efficiency of each target antibiotic at any rGO/$Bi_4O_5Br_2$ nanocomposites is greater than that of $Bi_4O_5Br_2$ nanosheet. $Bi_4O_5Br_2$ on the surface of the rGO/$Bi_4O_5Br_2$ nanocomposites can be excited to produce electrons (e^-) and holes (h^+) when illuminated by simulated sunlight. The photogenerated holes can react efficiently with the target antibiotics pollutant to degrade them, and to remove the photogenerated electron-hole pairs effectively. As a result of their excellent electron reservoir capability of rGO and conductivity, photogenerated electrons can be transferred quickly to the rGO/$Bi_4O_5Br_2$ nanocomposite surface to reacted with O_2, thus generating $.O_2^-$ radicals. Meanwhile, The instantaneous formation of .OH by the reaction of .O2 radicals and H+ is also possible. Following that, .O2 and .OH radicals can oxidize the target antibiotics adsorbed on the surface of the rGO/Bi4O5Br2 nanocomposite to complete the photodegradation process.

Fakhri and Bagheri, (2020) reported the fabrication of UiO-66@WG for the photocatalytic degradation tetracycline (TC) and malathion (MA). It was clearly reported by the authors that after photocatalytic efficiency of 84 and 100 % was achieved for TC and MA respectively, by UiO-66@35WG as an optimum photocatalyst after 70 min of irradiation. The UiO-66@35WG showed enhanced response to visible light, better separation of charge carriers, good contacting between energy levels of components, and more availability of active site that are responsible for its superior photodegradation efficiency in compared with pristine UiO-66. The photocatalytic mechanism verified that $O_2^{-\cdot}$ is main radical species involved in this process. Finally, the authors concluded that precise positioning of energy levels belonging to components and the formation of

an electrical field results in effective charge transfer and enhanced separation of electron-hole pairs, which is advantageous in a photocatalytic system.

Wang et al., (2022) explored the fabrication of magnetic cobalt ferrite/reduced graphene oxide (CF/rGO) porous balls for effective photocatalytic degradation of oxytetracycline. It was revealed that enhanced adsorption makes it easier for the photocatalyst to have strong interaction with OTC, thereby improving the degradation efficiency. Under visible light irradiation ($\lambda > 420$ nm), the light excited CF/rGO-0.2 to produce electron-hole pairs. h^+ exhibits strong oxidation capacity and can directly oxidize OTC. At the same time, electrons are captured by rGO, which effectively reduces the charge carrier recombination. In addition, the unique porous balls increase the light absorption capacity and provided more catalytic centers. Therefore, CF/rGO showed good photocatalytic activity in photocatalytic redox reaction with 84.7 % degradation efficiency. The trapping experiments revealed that holes (h^+) and superoxide radicals (O_2^-) played a crucial role in the degradation of OTC, implying a possible photocatalytic reaction mechanism.

The photocatalytic degradation of Tetracycline (TC) under visible-light using by reduced graphene oxide decorated MoO_3/TiO_2 nanocomposite was investigated by Ali et al., (2022). According to the authors, RGO decreases electron-hole pair recombination by functioning as an acceptor of photo-generated electrons from TiO_2/MoO_3 nanoparticles. As a result, it generates even more photo-generated holes, promoting the formation of reactive oxygen species and pollutant degradation. Surface imperfections on the TiO_2/MoO_3 surface of the RGO can retain electrons in this case, and the intermediate product can then replicate surface defects via interfacial charge transfer. The presence of defects that act as trapping centres can extend the lifetime of electrons or holes in metal oxide coupling, and photocatalytic activity rises as RGO concentration increases. The authors also reported that the excellent photo-degradation impact of TC via the $Gr/MoO_3/TiO_2$ was due to the synergetic (interfacial) interaction of the graphene sheets and the MoO_3/TiO_2. Furthermore, the MoO_3/TiO_2 was utilized as a migration vehicle for the visible light carrier, while the decreased graphene sheet's large surface area and number of active sites increased photocatalytic activity with almost 94 % TC photodegraded during 80 min under visible light irradiation.

Zhang et al., (2022b) studied the photodegradation performance tetracycline (TC) onto PG/TiO_2 under UV and visible light. The authors observed that TiO_2 photocatalytic activity was discovered to be closely linked to its surface phase, and the creation of a surface-phase junction between anatase and rutile may facilitate spatial charge separation. It was also observed that the PG might shift the light absorption edge from UV to visible light, resulting in additional photogenerated electron holes. Furthermore, there was a dual effect resulting from TiO_2 and PG combination which involves the enhancing adsorption of visible light while also improving the separation ability of e^- and h^+ to significantly inhibit e and h^+ recombination. The authors' proposed adsorption and photocatalytic mechanism is that, first, as an effective absorbent during dark conditions, the PG and TiO2 reactive interface would adsorb a large amount of TC molecules to the material's surface and into the confined area. Second, under visible and UV light, TiO2 was bombarded with energy higher than the band gap, while electrons (e-) in the valence band could absorb the photon energy causing them to migrate to the conduction band and form electropositive holes (h+) in the valence band. Thirdly, to prevent charge recombination, h^+ and e^- moved from the interior to the surface of PG, and the interface functioned as the activity sites. By interacting with H_2O, h^+ produced **.**OH, and electrons on the surface of PG/TiO_2 produce **.**O_2^- by absorbing **.**O_2^-. Lastly, the photocatalytic process involving active species ($\cdot O_2^-$, h^+, and ·OH) were involved in in redox reactions which were responsible for the removal of TC via degradation of its molecules to form smaller organic molecules, CO_2 and H_2O.

Ghorbanih and Salem, (2021) reported the performance of hybridized materials containing graphene oxide and carbon nanotubes (CNTs) to photocatalytically treat sewage released out of an industrial estate. Their findings revealed the capability of hybridized nanocomposites to treat the accumulated sewages at various steps of the industrial recovery process, between the anaerobic system and the sand filter. The suitable distribution ratio of graphene and CNTs were calculated to be 3.33 %. The end-result of parameters such as initial COD, period of irradiation, sewage collection position, as well as pH on treatment performance were investigated. The maximum photo-activity was reached in 20 min by keeping the pH of the sewage at 8. The authors consider larger surface area, of 60 m^2/g and lower band gap energy of 2.1 eV as responsible.

Ag_3PO_4-graphene and Ag_3PO_4-graphene/Ag was synthesized by Zhou et al. (2016) via chemical precipitation for the decomposition of sulfamethoxazole. Under synthetic solar radiation, 1ppm of

sulfamethoxazole was almost totally degraded in 30 min using the two photocatalysts. The integration of Ag on Ag_3PO_4-graphene did not show any reasonable upgrade in its Photocatalytic functionality for sulfamethoxazole decomposition as compared to its pure form. The contribution of the Ag load is therefore unclear and subject to further research. Hetero-junction composites.

Cao et al. (2016) found that photocatalytic degradation of tetracycline using magnetic-GO/Ce/TiO_2 degraded 82.9 % of the tetracycline. Priya et al. (2016) also accounted that ampicillin and oxytetracycline were photocatalytically degraded by Bi_2O_3/BiOCl reinforced on chitosan and graphene-sand composite, with 95 % ampicillin removal attained in 1 h solar light (Ajala et al., 2022).

The photocatalyst revealed 90% TC adsorption under visible light radiation (Chen et al., 2017). This is higher than those obtained from $BiVO_4$, Ag_3PO_4/$BiVO_4$, and RGO/$BiVO_4$ which showed 56, 82 and 78 % adsorption respectively.

Wang et al. (2017) successfully developed a C_3N_4/$MnFe_2O_4$/graphene composite for antibiotic degradation. The four antibiotics studied were metronidazole, amoxicillin, tetracycline, and ciprofloxacin, and C_3N_4@$MnFe_2O_4$-grephene composites removed 94.5 % of metronidazole, which was approximately 3.5 times greater than pure g-C_3N_4.

Guan et al., (2021) successfully fabricated Z-scheme photocatalyst for TC-hydrochloride decomposition using Bi2WO6 nanosheets, graphene oxide, and silver bromide nanomaterials. The modified Z-scheme composite (15 %AgBr/5GO/Bi_2WO_6 (15A/5G/BW) showed increased intersurface charge separation and transmission because of GO's exceptional electrical conductivity. Consequently, 15A/5G/BW showed the best TC-hydrochloride photocatalytic activities. Under visible light radiation, the peak decomposition effectiveness of 84 %, and the kinetic constant was found to be greater at 0.0515 min (approximately 4.60 and 3.16 times) than that of AgBr and Bi_2WO_6, respectively.

BiOBr/MoS_2/Graphene oxide (Bismuth-oxybromide/molybdenum disulfide/GO) fabrication was reported used by Li et al., (2021) to modify the capability of photocatalytic decomposition and adsorption of oxytetracycline (OTC). The composites exhibited an excellent photocatalytic functionality for oxytetracycline decomposition. In the presence of visible light radiation, oxytetracycline, doxycycline, chloro-TC were spontaneously adsorbed with over 98 %

decomposition rate in 40 min. Further studies can be undertaken taking into consideration the benefits of ion-doping and coupled-semiconductors towards improving Photocatalytic activity and graphene composite synthesis.

Alamgholiloo et al., (2021) fabricated a novel and effective GO/CuBDC-Fe_3O_4 ternary nanocomposite for ciprofloxacin (CIP) degradation. According to the authors, the ternary nanocomposite demonstrated the highest CIP degradation rate (98.5 %) in 24 min, with a rate constant of 0.191 min^{-1}. The results showed that Cu/Fe species and C=O groups in ternary nanocomposite catalyzed PMS to the generation of hydroxyl and sulfate radicals for CIP decomposition. Moreover, the ternary nanocomposite demonstrated a high possibility of regeneration, allowing the catalyst to be easily separated from reaction mixtures with an external magnet. However, radical quenching tests and electron paramagnetic resonance (EPR) showed that hydroxyl and sulphate ions play an important part in the decomposition process.

According to Hsieh et al., (2022), recent advances have been made in the treatment of wastewater from industrial and medical sector. Untreated antibiotics, which are easily seen in effluents released by hospitals and manufacturers alike, have drawn the attention of environmentalists. The authors developed graphene quantum dot/ZnO composites that were used as a photocatalyst for metronidazole degradation. The results revealed an ultra-high removal efficiency (100 %) and a substantially increased reaction rate constant that was 1.74 times above the pristine sample. In summary, N-GQDs improve visible-light absorption and increase photo-induced charge carriers. This is due to the N-functionalized GQDs having a smaller optical band gap (3.0 to 3.5 eV) thereby propelling charge transfer in the heterostructure, improving photocurrent generation, and restricting electron-hole recombination from pristine ZnO crystals exposed to UV light.

8. Recyclability of graphene-based nanomaterials

Due to its low economic cost and environmental sustainability, graphene has been widely applied in industrial applications. High quality product yield at minimal cost implication is a major consideration in any industrial process. However, as compared to lab-scale conditions, the industrial application is tougher and more complex. The stability and reusability of graphene must therefore be high for it to be considered for continuous process development for industrial application (Das et al., 2018). A major advantage of graphene-based nanomaterials is their

stableness, recyclability, and ability to regenerate from a solution. High adsorption capability should not be the only criteria for an excellent adsorbent but also outstanding desorption capacity which will significantly increase the effectiveness and reduce operational cost. Therefore, reusability and desorption are pertinent for graphene-based nanomaterials to be applied commercially (Peng et al., 2017). graphene-based adsorbents must be subjected to separation from the medium, regeneration and recycling after utilization in effluent decontamination. The small particle size of these sorbents makes it difficult and strenuous to separate (Verma and Nadagouda, 2021). Although RGO is derived from GO, it differs significantly from GO in terms of thermophysical properties. As a result of the oxygen-containing functional groups present in GO, phonon scattering occurs, resulting in extremely low thermal conductivity of GO. However, oxygen-containing functional groups can be removed to some extent, and thermal conductivity will be increased following the reduction process (Zhou et al., 2022). Several methods have been deployed to efficiently separate graphene-based sorbents from wastewater, among which the most handing is centrifugation, crossflow filtration, field-flow fractionation, and electric field (Ali et al., 2018; Kim et al., 2006).

Mu et al. (2017) also described the development of 3-Dimensional nanostructured composite sorbents of RGO and WO_3 (RGO/WO_3) for the removal of strontium ion (Sr^{2+}) from aqueous solutions. Adsorption isotherms reveal the experimental data well fitted the Langmuir isotherm ($R > 0.99$), and the peak adsorption capability of 149.56 mg/g was attained, which is m greater than that of GO, WO_3, and other close-related sorbents. Treatment of Sr^{2+} by RGO/WO_3 attained equilibrium in 3h, 20min. The abundant treatment sites made available by the diffused WO_3 nanoparticles on the Reduced Graphene Oxide surface made treatment rate faster and higher for RGO/WO_3. Moreso, the presence of sodium ions has no discernible impact on the adsorption of Sr2+ ions on RGO/WO_3, and the adsorption-desorption experiment with RGO/WO_3 sorbent is recyclable at least 5 times without substantial adsorption capability loss.

Xiao et al., (2019) investigated desorption of antibiotics from prepared molybdenum di-sulfide graphene-oxide supported magnetic nanoparticles (Fe_3O_4/GO/MoS_2) using Acetonitrile (CAN) as eluent. Desorption was obtained as 90.2, 87.8 and 85.6 % for Pazcofloxacin, Lecofloxacin, and Gatifloxacin respectively. They also carried out reusability tests under ideal conditions. The study's

findings revealed that the Fe_3O_4/GO/MoS_2 material could be reused 10 times without significant loss.

Qiao et al., (2020) synthesized MGO/ZnO nanocomposites (MZ) which was used in the removal of tetracycline (TC). The maximum adsorption capability of 1590.28 mg g^{-1} observed in their study. Recyclability studies showed that MZ could be recycled up to four times with no apparent decrease in photocatalytic activity resulting from incomplete desorption of TC.

Alamgholiloo et al., (2021) used a green solvothermal technique to fabricate a novel ternary nanocomposite (GO/CuBDC-Fe_3O_4) which was employed in degrading ciprofloxacin (CIP) antibiotic. A 98.5% removal rate was observed for CIP and still showed good degradation capability after four cycles, signifying the stability of the catalyst.

The synergistic effect of magnetic particle coupling with graphene or GO can be the panacea to resolving the challenges that graphene separation poses. According to Bulin et al., (2020) and Ma et al., (2021), magnetization enables the practical use of GO in the production of adsorbents This is because very little energy is required which can be achieved by the use of an external magnetic field to provide excellent separation (Wang et al., 2021). The high chemical stability of Magnetic-graphene oxide (MGO) and its nanocomposites make it desirable and gradually position itself as an emergent and efficient treatment technology. The efficacy of MGO has been studied and can be used extensively in treating aqueous biomedical effluents including radionuclides and antibiotics- a contaminant of emerging concern. Moreover, MGO has good hydrophilic and magnetic properties and has been observed to be more stably dispersed in aqueous solution. In addition, it reduces the chances of severe agglomeration and nanosheet restacking, allowing for easy solid-liquid separation process. MGO is created by modifying magnetic materials such as ferric oxide to GO (Wang et al., 2021b). MGO can be made reusable by treatment mineral acids and bases (at low concentration), such as HCl, HNO_3 NaOH and sodium carbonate. The capacity for adsorption and regeneration is equal or even greater than other sorbents when compared.

Ullah et al., (2022) synthesized reduced-MGO/polyaniline (RmGO/PANI) as a sorbent for the adsorption of moxifloxacin (MOX) and ofloxacin (OFL) from the aqueous samples. They achieved adsorption efficacy of 99% for MOX and 96 % for OFL. The adsorbent was reused repeatedly 10 times maintaining an excellent removal capacity.

Shi et al., (2020) synthesized CdS/reduced graphene (rGO)/$ZnFe_2O_4$ (ZFO) nanocomposite system to attain efficacious Photo-Fenton decomposition of tetracycline (TC) in the presence of visible light radiation. The authors found out that CdS/rGO/ZFO composite material adsorbed 80 % of TC mineralized at a 59.2 % in 1 hour, attributable to the photo-Fenton synergistic effect in CdS/rGO/ZFO with the capacity of producing and degrading H_2O_2. Meanwhile, the CdS/rGO/ZFO photocatalyst's prominent magnetic recovery property ensured economic benefits. The CdS/rGO/ZFO adsorbent was reused after 4 cycles. The Recyclability of graphene-based nanomaterials based on cycle of used with various biomedical pollutants is presented in Table 6.

Table 6: Recyclability of graphene-based nanomaterials based on cycle of used.

Graphene nanocomposite	Pollutant/removal condition	Eluent used	Recovery	Cycle of used	References
MGO/ZnO* nanocomposites (MZ)	Tetracycline 100 min 1590.28 mg g-1	NaOH	80 %	4	Qiao et al., (2020)
Co-Fe-PBAs@rGO*	Levofloxacin Hydrochloride	-	83.7 %	5	Pi et al., (2018)
GO/CuBDC-Fe3O4	ciprofloxacin (CIP) 98.5%			4	Alamgholiloo et al., (2021)
GOMPs	Tetracycline 10 min 98%	Ethanol		5	Lin et al., (2013b)
RmGO/PANI	moxifloxacin (MOX) – 99% ofloxacin (OFL) – 96 %		-	10	Ullah et al., (2022)
Fe3O4/GO/MoS2	Pazcofloxacin-90.2% Lecofloxacin-87.8%, Gatifloxacin-85.6%	ACN		10	Xia et al., 2019
Cds/rGO//ZFO	Tetracycline 60 min 80%			4	Shi et al., 2022
AgFeO2/GO	Lomefloxacin 75 mins 88%			3	Yashas et al., 2021
PVDF-PB-GO membrane	137Cs 79.6%	NH_4Cl HNO_3		5	Zhang et al., (2022a)
RGO/WO3	Sr2+ 100%	HCl, HNO_3, H_2SO_4		5	Mu et al., (2022)

CedopedCo34/RGO[x]	Tetracycline 10 mins 90%			3	Pervaiz et al., (2022)
MGO@PANI	CIP 30 min 97%	Methanol 80 ^{o}C 2hrs	94.5 % 75 %	5 10	Nodeh et al., (2018)
LDH/GO[x]	Gatifloxacin 60mins 98%	-		4	Deng et al., (2021)
Nitrogen-doped reduced graphene oxide beads (NrGOb) [x]	hydroxybenzoic acid 90 mins 100%	Peroxymonosulfate (PMS) solution for 1 h followed by ultrapure water		3	Hirani et al., (2022)
Graphene oxide nanosheet (GOS)	Sulfamethoxazole 110mins 122mgg^{-1}				Rostamian and Behnejad (2016)
Magnetic Graphene Oxide (nGO)	Clonazepam 180mins 14.41mgg^{-1}	HCl	90 %	5	Nascimento et al., (2022)

[x]catalytic degradation;

9. Future Perspectives

The potential of graphene and its composites in wastewater treatment application towards the removal of biomedical pollutants and toxic compounds is significant. Novel treatment methods were developed years ago and their performance can be improved by incorporating novel functional materials like GO and graphene-based nanoparticles. Simultaneous adsorption and photodegradation is now seen as a new strategy in biomedical wastewater treatment beyond phase transfer offering degradation and possible mineralization of pollutants. Studying the influential factors and underlying mechanism that accompany the treatment process will also go a long way to improve the understanding and subsequent applicability of these materials. Researchers are also beginning to introduce graphene and its derivatives into traditional photocatalyst like ZnO and TiO_2. The success of this hybrid nanoparticle has been validated by recent research which positions it as one of the most promising technologies in wastewater decontamination and treatment (Nazal et al., 2020; Gao et al., 2020; Zheng et al., 2020). However, the treatment efficacy for real biomedical waste considering the presence of multiple contaminants is yet unknown and should be further looked into. Little work relating to process optimization methods such as Taguchi and response surface methodology have been carried out. Research on optimal conditions that ensure

maximum treatment efficiency is encouraged if full scale deployment and industrial application is going to be achieved. Life cycle assessment studies that map out raw material acquisition, synthesis, use, and disposal are encouraged to reduce its environmental impact and ensure sustainability.

10. Conclusion

The benefits of medicine and medical healthcare are undisputed; however, production and extensive use has resulted in waste generation and biomedical pollution. With current innovation, development and advanced medical technology, there are new challenges such as biomedical waste management. For instance, the amount of waste generated during production of pharmaceuticals varies greatly in amount and type (~200 to 30,000 kg of wastes per kg of active ingredients can be generated), relatively higher than the actual finished product. Existing treatment methods cannot meet quality threshold values regulations while government authorities impose stricter measures. Medical facilities are thus faced with challenges associated with adequate treatment of the waste and effluents they generate. More advanced technologies have been sought as conventional methods can no longer handle emerging contaminants vis-à-vis the stricter regulatory guidelines. High surface area, improved chemical properties, lower cost, and high regeneration capacity for reuse make nanomaterials advantageous for treatment processes in wastewater management and decontamination. Graphene and graphene oxide (GO) are a unique nanomaterial for water and wastewater treatment. They possess inherent chemical and physicochemical properties such as good biocompatibility, high surface area, optical, thermal and electrical conductivities, making them unique and very suitable for decontaminating wastewater. Nevertheless, little has been extensive research for possibility of its application in biomedical waste treatment except for antibiotics and related metabolites.

Acknowledgement

The authors acknowledge the Ministry of Higher Education (MOHE), Malaysia for providing the research funding under project code FRGS/1/2019/TK10/CURTIN/02/2. We also thank Curtin University Malaysia for providing research facility and financial support for the project.

Funding

Fundamental Research Grant Scheme (FRGS) under project code FRGS/1/2019/TK10/CURTIN/02/2

Author Contributions

Kehinde Shola Obayomi: Conceptualization, Methodology, Writing Original draft preparation. Sie Yon Lau: Supervision, Validation, Resources. Ibitogbe Enoch Mayowa: Writing, Reviewing and Editing. Michael K. Danquah: Writing, Reviewing and Editing. Jianhua Zhang: Writing, Reviewing and Editing. Tung Chiong: Writing, Reviewing and Editing. Takeo Masahiro: Writing, Reviewing and Editing.

References

Acheson, E. G., 1896. Manufacture of Graphite. US patent 568323. 1896.

Ahmad, S. Z. N., Salleh, W. N. W., Ismail, A. F., Yusof, N., Yusop, M. Z. M., Aziz, F., 2020. Adsorptive removal of heavy metal ions using graphene-based nanomaterials: Toxicity, roles of functional groups and mechanisms, Chemosphere, 248, 126008.

Aghamohammadi, H., Eslami-Farsani, R., Torabian, M., Amousa, N., 2020. Recent advances in one pot functionalization of graphene using electrochemical exfoliation of graphite: a review study, Synthetic Metals, 269, 116549.

Agrawal, P., Kaur, G., Kolekar, S. S., 2021. Investigation on biomedical waste management of hospitals using cohort intelligence algorithm, Soft Computing Letters, 3, 100008.

Ahmed, M. B., Zhou, J. L., Ngo, H. H., Guo, W., Thomaidis, N. S., Xu, J., 2017. Progress in the biological and chemical treatment technologies for emerging contaminant removal from wastewater: a critical review. Journal of hazardous materials, 323, 274-298.

Ajala, O. J., Tijani, J. O., Bankole, M. T., Abdulkareem, A. S., 2022. A critical review on graphene oxide nanostructured material: Properties, Synthesis, characterization and application in water and wastewater treatment, Environmental Nanotechnology, Monitoring and Management, 18, 100673.

Alamgholiloo, H., Pesyan, N. N., Mohammadi, R., Rostamnia, S., Shokouhimehr, M. 2021. Synergistic advanced oxidation process for the fast degradation of ciprofloxacin antibiotics

using a GO/CuMOF-magnetic ternary nanocomposite. Journal of Environmental Chemical Engineering, 9(4), 105486.

Ali, I., Basheer, A. A., Mbianda, X. Y., Burakov, A., Galunin, E., Burakova, I., Mkrtchyan, E., Tkachev, A., Grachev, V., 2019. Graphene based adsorbents for remediation of noxious pollutants from wastewater, Environmental International, 127, 160-180.

Ali, A., Shoeb, M., Li, Y., Li, B., Khan, M. A., 2021. Enhanced photocatalytic degradation of antibiotic drug and dye pollutants by graphene-ordered mesoporous silica (SBA 15)/TiO_2 nanocomposite under visible-light irradiation Journal of Molecular Liquids, 324, 114696.

Ali, A., Shoeb, M., Li, B., Khan, M. A., 2022. Photocatalytic degradation of antibiotic drug and dye pollutants under visible-light irradiation by reduced graphene oxide decorated MoO_3/TiO_2 nanocomposite, Materials Science in Semiconductor Processing, 150, 106974.

AL-Othman, Z. A., AlMasoud, N., Mbianda, X. Y., Ali, I., 2022. Synthesis and characterization of γ-cyclodextrin-graphene oxide nanocomposite: Sorption, kinetics, thermodynamics and simulation studies of tetracycline and chlortetracycline antibiotics removal in water, Journal of Molecular Liquids, 345, 116993.

Al-Jubouri, S. M., Al-Jendeel, H. A., Rashid, S. A., Al-Batty, S., 2022. Antibiotics adsorption from contaminated water by composites of ZSM-5 zeolite nanocrystals coated carbon, Journal of Water Process Engineering, 47, 2022, 102745.

Al-Khateeb, L. A., Almotiry, S., Salam, M. A., 2014. Adsorption of pharmaceutical pollutants onto graphene nanoplatelets, Chemical Engineering Journal, 248, 191-199.

ALOthman, Z. A., AlMasoud, N., Mbianda, X. Y., Ali, I., 2022. Synthesis and characterization of γ-cyclodextrin-graphene oxide nanocomposite: Sorption, kinetics, thermodynamics and simulation studies of tetracycline and chlortetracycline antibiotics removal in water, Journal of Molecular Liquids, 345, 116993.

Alshamkhani, M. T., Teong, L. K., Putri, L. K., Mohamed, A. R., Lahijani, P., Mohammadi, M., 2021. Effect of graphite exfoliation routes on the properties of exfoliated graphene and its photocatalytic applications, Journal of Environmental Chemical Engineering 9, 106506.

Amine, A. E. K. 2013. Extended spectrum beta-lactamase producing bacteria in waste water alexandria, Egypt. International Journal of Bioscience, Biochemistry and Bioinformatics, 3(6), 605.

Amiria, A., Naraghib, M., Ahmadic, G., Soleymanihaa, M., Shanbedid, M., 2018. A review on liquid-phase exfoliation for scalable production of pure graphene, wrinkled, crumpled and functionalized graphene and challenges, FlatChem, 8, 40-71.

Andrade, M. B., Santos, T. R. T., Guerra, A. C. S., Silva, M. F., Demiti, G. M. M., Bergamasco, R., 2022. Evaluation of magnetic nano adsorbent produced from graphene oxide with iron and cobalt nanoparticles for caffeine removal from aqueous medium, Chemical Engineering and Processing - Process Intensification, 170, 108694.

Anirudhan, T.S., Deepa, J.R., Nair, A.S., 2017a. Fabrication of chemically modified graphene oxide/nano hydroxyapatite composite for adsorption and subsequent photocatalytic degradation of aureomycine hydrochloride. Journal of Industrial and Engineering Chemistry, 47, 415-430.

Anuma, S., Mishra, P., Bhat, B. R., 2021. Polypyrrole functionalized Cobalt oxide Graphene (COPYGO) nanocomposite for the efficient removal of dyes and heavy metal pollutants from aqueous effluents Journal of Hazardous Materials, 416, 125929.

Ara, L., Billah, W., Bashar, F., Mahmud, S., Amin, A., Iqbal, R., Rahman, T., Alam, N. H., Sarker, S. A., 2022. Effectiveness of a multi-modal capacity-building initiative for upgrading biomedical waste management practices at healthcare facilities in Bangladesh: a 21st century challenge for developing countries, Journal of Hospital Infection, 121, 49-56

Assouik, J., Hajji, L., Boukir, A., Herold, C., Lagrange, P., 2016. Synthesis, structure, and electrical behavior of the heavy alkali metal-arsenic alloys-based graphite intercalation compounds, Synthetic Metals, 218, 34-42.

Aunkor, M. T. H., Mahbubul, I. M., Saidur, R., Metselaar, H. S. C. 2016. The green reduction of graphene oxide, RSC Advances, 6 (33), 27807–27828.

Awad, A. M., Jalab, R., Benamor, A., Nasser, M. S., Ba-Abbad, M. M., El-Naas, M., Mohammad, A., 2020. Adsorption of organic pollutants by nanomaterial-based adsorbents: An overview, Journal of Molecular Liquids, 301, 112335.

Baig, N., Sajid, M., Saleh, T. A. 2019. Graphene-based adsorbents for the removal of toxic organic pollutants: A review. Journal of environmental management, 244, 370-382.

Balasubramani, K., Sivarajasekar, N., Naushad, M., Effective adsorption of antidiabetic pharmaceutical (metformin) from aqueous medium using graphene oxide nanoparticles: Equilibrium and statistical modelling, 2020. Journal of Molecular Liquids, 301, 1 March 2020, 112426.

Basagni, A., Sedona, F., Pignedoli, C. A., Cattelan, M., Nicolas, L., Casarin, M., Sambi, M., 2015. Molecules–Oligomers–Nanowires–Graphene Nanoribbons: A Bottom-Up Stepwise On-Surface Covalent Synthesis Preserving Long-Range Order, Journal of Physical Chemistry C, 137, 5.

Baumgarten, S., Schröder, H. F., Charwath, C., Lange, M., Beier, S., Pinnekamp, J., 2007. Evaluation of advanced treatment technologies for the elimination of pharmaceutical compounds. Water science and technology, 56(5), 1-8.

Bharath, G., Alhseinat, E., Ponpandian, N., Khan, M. A., Siddiqui, M. R., Ahmed, F., Alsharaeh, E. H., 2017. Development of adsorption and electrosorption techniques for removal of organic and inorganic pollutants from wastewater using novel magnetite/porous graphene-based nanocomposites, Separation and Purification Technology, 188, 206-218.

Bhuyan, M, S, A., Uddin, M. N., Islam, M. M., Bipasha, F. A., Hossain, S. S., 2016. Synthesis of graphene, International Nano Letters, 6, 65.

Biswal, S. (2013). Liquid biomedical waste management: An emerging concern for physicians. Muller Journal of Medical Sciences and Research, 4(2), 99.

Bo, Z., Shuai, X., Mao, S., Yang, H., Qian, J., Chen, J., 2014. Green preparation of reduced graphene oxide for sensing and energy storage applications, Scientific Report. 4, 4684.

Brodie, B.C., 1859. On the atomic weight of graphite. Philos. Trans. Roy. Soc. Lond.149, 249-259.

Bouhafs, C., Pezzini, S., Geisenhof, R. F., Mishra, N., Mišeikis, V., Niu, Y., Struzzi, C., Weitz, R. T., Forti, S., Coletti, C., 2022. Synthesis of large-area rhombohedral few-layer graphene by chemical vapor deposition on copper, Carbon, 177, 282-290.

Bulin, C., Zhang, Y., Li, B., Zhang, B. 2020. Removal performance of aqueous Co (II) by magnetic graphene oxide and adsorption mechanism. Journal of Physics and Chemistry of Solids, 144, 109483.

Cao, M., Wang, P., Ao, Y., Wang, C., Hou, J., Qian, J., 2016. Visible light activated photocatalytic degradation of tetracycline by a magnetically separable composite photocatalyst: Graphene oxide/magnetite/cerium-doped titania, Journal of Colloid and Interface Science, 467, 129-139.

Carballa, M. Omil, F. and Lema, J. M., 2008. Comparison of predicted and measured concentrations of selected pharmaceuticals, fragrances and hormones in Spanish sewage, Chemosphere, 72: 1118–1123

Chao, Y., Tang, B., Luo, J., Wu, P., Tao, D., Chang, H., Chu, X., Huang, Y., Li, H., Zhu, W. 2021. Hierarchical porous boron nitride with boron vacancies for improved adsorption performance to antibiotics, Journal of Colloid Interface Science, 584, 154-163.

Chartier, Yves, ed. Safe management of wastes from health-care activities. World Health Organization, 2014.

Chen, J., Yao, B., Li, C., Shi, G., 2013. An improved Hummers method for eco-friendly synthesis of graphene oxide, Carbon, 64, 225-229.

Chen, F., Yang, Q., Li, X., Zeng, G., Wang, D., Niu, C., Zhao, J., An, H., Xie, T., Deng, Y., 2017. Hierarchical assembly of graphene-bridged Ag_3PO_4/Ag/$BiVO_4$ (040) Zscheme photocatalyst: an efficient, sustainable and heterogeneous catalyst with enhanced visible-light photoactivity towards tetracycline degradation under visible light irradiation, Applied Catalysis B: Environmental, 200, 330-342.

Chen, F., Liang, W., Qin, X., Jiang, L., Zhang, Y., Fang, S., Luo, D., 2021. Preparation and recycled simultaneous adsorption of methylene blue and Cu^{2+} co-pollutants over carbon layer encapsulated Fe_3O_4 /graphene oxide nanocomposites rich in amino and thiol groups, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 625, 126913.

Choi, W., Lahiri, I., Seelaboyina, R., Kang, Y. S., 2010. Synthesis of graphene and its applications: a review, Critical Review in Solid State 35 (1), 52–71.

Choucair, M., Thordarson, P., Stride, J. A., 2009. Gram-scale production of graphene based on solvo thermal synthesis and sonication, Nature Nanotechnology, 4 (1), 30–33.

Ciesielski, A., Samorì, P., 2014. Graphene via sonication assisted liquid-phase exfoliation, Chemical Society Reviews 43 (1), 381–398.

Compton, O. C., An, Z., Putz, K. W., Hong, B. J., Hauser, B. G., Brinson, L. C., Nguyen, S. T., 2012. Additive-free hydrogelation of graphene oxide by ultrasonication, Carbon, 50 (10), 3399-3406.

Coraux, J., N'Diaye, A. T., Busse, C., Michely, T., 2008. Structural coherency of graphene on Ir(111), Nano Letters, 8 (2), 565–570.

Crini, G., and Lichtfouse, E., 2019. Advantages and disadvantages of techniques used for wastewater treatment. Environmental Chemistry Letters, 17, 1, 145-155.

Das, R., Talat, M., Srivastava, O. N., Kayastha, A. M., 2018. Covalent immobilization of peanut β-amylase for producing industrial nanobiocatalysts: A comparative study of kinetics, stability and reusability of the immobilized enzyme, Food Chemistry, 245, 488-499.

Dash, K., Das, M., Satapathy, N. K., 2021. Assessment of knowledge, attitude, and practices about biomedical waste management among nursing professionals in a Tertiary Care Hospital, Bhubaneswar, Odisha, European Journal of Molecular & Clinical Medicine, 8 (3), 1127-1142.

Deng, J., Xiao, L., Yuan, S., Wang, W., Zhan, X. and Hu, Z.H., 2021. Activation of peroxymonosulfate by CoFeNi layered double hydroxide/graphene oxide (LDH/GO) for the degradation of gatifloxacin. Separation and Purification Technology, 255, 117685.

Dulama, M., Deneanu, N., Dulama, C., Pavelescu, M. 2008. Experimental studies concerning the semipermeable membrane separation efficiency for Cs-134, Cs-137, Co-57, Co-58, Co-60, Mn-54 in liquid radioactive waste. Rev Chim, 59, 544-549.

Ebratkhahan, M., Zarei, M., Akpinar, I. Z., Metin, O., 2022. One-pot synthesis of graphene hydrogel/M (M: Cu, Co, Ni) nanocomposites as cathodes for electrochemical removal of rifampicin from polluted water, Environmental Research, 214, 113789.

Elmolla, E. S., Chaudhuri, M., 2010. Photocatalytic degradation of amoxicillin, ampicillin and cloxacillin antibiotics in aqueous solution using UV/TiO_2 and UV/H_2O_2/TiO_2 photocatalysis, Desalination, 252, (1–3), 46-52.

Ersan, G., Apul, O. G., Perreault, F., Karanfil, T., 2017. Adsorption of organic contaminants by graphene nanosheets: A review, Water Research, (126), 385-398.

Fakhri, H., Bagheri, H., 202O. Highly efficient Zr-MOF@WO_3/graphene oxide photocatalyst: Synthesis, characterization and photodegradation of tetracycline and malathion, Materials Science in Semiconductor Processing, 107, 104815.

Fang, M., Wang, K., Lu, H., Yang, Y., Nutt, S., 2009. Covalent polymer functionalization of graphene nanosheets and mechanical properties of composites, Journal of Materials Chemistry, 19 (38), 7098–7105.

Feng, J-B., Li, Y-Y., Zhang, Y., Xu, Y-Y., Cheng, X-W., 2022. Adsorptive removal of indomethacin and diclofenac from water by polypyrrole doped-GO/COF-300 nanocomposites, Chemical Engineering Journal, 429, 132499.

Figueiredo, B. R., Cardoso, S. P., Portugal, I., Rocha, J., Silva, C. M. (2018). Inorganic ion exchangers for cesium removal from radioactive wastewater. Separation and Purification Reviews, 47(4), 306-336.

Freundlich, H. M. F., 1906. Over the adsorption in solution, Journal of Physical Chemistry, 57, 385–471.

Gadipelly, C., Pérez-González, A., Yadav, G.D., Ortiz, I., Ibáñez, R., Rathod, V.K. Marathe, K.V., 2014. Pharmaceutical industry wastewater: review of the technologies for water treatment and reuse. Industrial & Engineering Chemistry Research, 53, 29, 11571-11592.

Gao, Y., Li, Y., Zhang, L., Huang, H., Hu, J., Shah, S. M., Su, X. 2012. Adsorption and removal of tetracycline antibiotics from aqueous solution by graphene oxide. Journal of colloid and interface science, 368(1), 540-546.

Gao, E., Lin, S.-Z., Qin, Z., Buehler, M. J., Feng, X.-Q., Xu, Z., 2018. Mechanical exfoliation of two-dimensional materials, Journal of Mechanics, and Physics of Solids, 115, 248-262.

Gao, Z., Wang, S., Berry, J., Zhang, Q., Gebhardt, J., Parkin, W. M., Avila, J., Yi, H., Chen, C., Hurtado-Parra, S., Drndić, M., Rappe, A. M., Srolovitz, D. J., Kikkawa, J. M., Luo, Z., Asensio, M. C., Wang, F., Johnson, A, T. C., 2020. Large-area epitaxial growth of curvature-stabilized ABC trilayer graphene, Nature Communications, 11, 546,

Ghorbanih, M., Salem, S., 2021. Removal of chemical oxygen demand from industrial estate sewage over hybridized anatase-graphene oxide-carbon nanotubes nanocomposite under solar irradiation, Process Safety and Environmental Protection, 149, 581-590.

Grisales-Cifuentes, C. M., Galvis, E. A. S., Porras, J., Flórez, E., Torres-Palma, R. A., Acelas, N., 2021. Kinetics, isotherms, effect of structure, and computational analysis during the removal of three representative pharmaceuticals from water by adsorption using a biochar obtained from oil palm fiber, Bioresource Technology, 326, 124753.

Guan, Z., Li, X., Wu, Y. Chen, Z., Huang, X, Wang, D., Yang, Q., Liu, J., Tian, S., Chen, X., Zhao, H., 2021. AgBr nanoparticles decorated 2D/2D GO/Bi_2WO_6 photocatalyst with enhanced photocatalytic performance for the removal of tetracycline hydrochloride, Chemical Engineering Journal, 410, 128283.

Guo, W., Cheng, D., Ngo, H. H., Chang, S. W., Nguyen, D. D., Nguyen, D. P., Bui, X. T. 2020. Anaerobic membrane bioreactors for antibiotic wastewater treatment. In Current Developments in Biotechnology and Bioengineering, 219-239.

Haiba, E., Lillenberg, M., Kipper, K., Herodes, K. (2013). Degradation of some pharmaceuticals during sewage sludge composting. Global Journal on Advances Pure and Applied Sciences, 1.

Han, Z., Xiao, X., Qu, H., Hu, M., Au, C., Nashalian, A., Xiao, X., Wang, Y., Yang, L., Jia, F., Wang, T., Ye, Z., Servati, P., Huang, L., Zhu, Z., Tang, J., Chen, J., 2022. Ultrafast and Selective Nanofiltration Enabled by Graphene Oxide Membranes with Unzipped Carbon Nanotube Networks, ACS Applied Materials and Interfaces, 14(1),1850–1860.

Hernandez, Y., Lotya, M., Rickard, D., Bergin, S. D., Coleman, J. N., 2010. Measurement of multicomponent solubility parameters for graphene facilitates solvent discovery, Langmuir 26 (5) 3208–3213.

Hernandez, Y., Nicolosi, V., Lotya, M., Blighe, F. M., Sun, Z., De, S., et al., 2008. High-yield production of graphene by liquid-phase exfoliation of graphite, Nature Nanotechnology, 3, 563–568.

Hiew, B. Y. Z., Lee, L. Y., Lee, X. J., Gan, S., Thangalazhy-Gopakumar, S., Lim, S. S., Pan, G-T., Yang, T. C-K., 2019. Adsorptive removal of diclofenac by graphene oxide: Optimization, equilibrium, kinetic and thermodynamic studies, Journal of the Taiwan Institute of Chemical Engineers, 98, 150-162.

Hirani, R.A.K., Asif, A.H., Rafique, N., Wu, H., Shi, L., Zhang, S., Duan, X., Wang, S., Saunders, M. and Sun, H., 2022. Three-dimensional nitrogen-doped graphene oxide beads for catalytic degradation of aqueous pollutants, Chemical Engineering Journal, 446(2), 137042.

Ho, Y. S., McKay, S., 1999. Pseudo-second order model for sorption processes, Process Biochemistry, 34, 451–465.

Homem, V., Santos, L., 2011. Degradation and removal methods of antibiotics from aqueous matrices-a review, Journal of Environmental Management., 92, 2304-2347

Hooshmand, S., Kargozar, S., Ghorbani, A., Darroudi, M., Keshavarz, M., Baino, F., Kim, H. W. 2020. Biomedical waste management by using nanophotocatalysts: The need for new options. Materials, 13(16), 3511.

Hossain, M. F., Akther, N., Zhou, Y., 2020. Recent advancements in graphene adsorbents for wastewater treatment: Current status and challenges, Chinese Chemical Letters, 3110, 2525-2538.

Hosseini, H., Zirakjou, A., McClements, D. J., Goodarzi, V., Chen, W-H., 2022. Removal of methylene blue from wastewater using ternary nanocomposite aerogel systems: Carboxymethyl cellulose grafted by polyacrylic acid and decorated with graphene oxide, Journal of Hazardous Materials, 421, 126752.

Hsieh, M-L., Juang, R-S., Gandomi, Y-A., Fu, C-C., Hsieh, C-T., Liu, W-R., 2022. Synthesis and characterization of high-performance ZnO/graphene quantum dot composites for photocatalytic degradation of metronidazole, Journal of the Taiwan Institute of Chemical Engineers, 131, 104180.

Hummers, W. S., Offeman, R. E., 1958. Preparation of graphitic oxide, J. Am. Chem. Soc. 80 1339.

Huang, B., Wang, H. C., Cui, D., Zhang, B., Chen, Z. B., & Wang, A. J. 2018. Treatment of pharmaceutical wastewater containing β-lactams antibiotics by a pilot-scale anaerobic membrane bioreactor (AnMBR). Chemical Engineering Journal, 341, 238-247.

Huo, P., Zhou, M., Tang, Y., Liu, X., Ma, C., Yu, L., Yan, Y., 2016. Incorporation of NZnO/ CdS/Graphene oxide composite photocatalyst for enhanced photocatalytic activity under visible light, Journal of Alloys and Compounds, 670, 198-209.

Ikram, R., Jan, B. M., Ahmad, W., 2020. Advances in synthesis of graphene derivatives using industrial wastes precursors; prospects and challenges, Journal of Materials Research and Technology, 9, (6), 15924-15951.

Innemanová, P., Grasserová, A., Cajthaml, T. 2022. Pilot-scale vermicomposting of dewatered sewage sludge from medium-sized wwtp. detritus, 18, 35.

International Atomic Energy Agency. (2000). Management of radioactive waste from the use of radionuclides in medicine. International Atomic Energy Agency.

Iqbal, A. A., Sakib, N., Iqbal, A. K. M. P., Nuruzzaman, D. M., 2020. Graphene-based nanocomposites and their fabrication, mechanical properties, and applications, Materialia, 12, 100815.

Januário, E. F. D., Fachina, Y. J., Wernke, G., Demiti, G. M. M., Beltran, L. B., Bergamasco, R., Vieira, A. M. S., 2022. Application of activated carbon functionalized with graphene oxide for efficient removal of COVID-19 treatment-related pharmaceuticals from water, Chemosphere, Volume 289, 133213.

Jaswal, A., Kaur, M., Singh, S., Kansal, S. K., Umar, A., Garoufalis, C. S., Baskoutas, S., Adsorptive removal of antibiotic ofloxacin in aqueous phase using rGO-MoS_2 heterostructure, 2021. Journal of Hazardous Materials, 417, 125982.

Jeyaseelan, A., Ghfar, A. A., Naushad, M, Viswanathan, 2021. Design and synthesis of amine functionalized graphene oxide for enhanced fluoride removal Journal of Environmental Chemical Engineering, 9 (4), 105384.

Jia, F., Xiao, X., Nashalian, A., Shen, S., Yang, L., Han, Z., Qu, H., Wang, T., Ye, Z., Zhu, Z., Huang, L., Wang, Y., Tang, J., Chen, J., 2022. Advances in graphene oxide membranes for water treatment, Nano Research, 15, 6636–6654.

Juengchareonpoon, K., Wanichpongpan, P., Boonamnuayvitaya, B., 2021. Graphene oxide and carboxymethylcellulose film modified by citric acid for antibiotic removal, Journal of Environmental Chemical Engineering, 9(1), 104637.

Julkapli, N.M., Bagheri, S., 2015. Graphene supported heterogeneous catalysts: an overview, International Journal of Hydrogen Energy, 40, 948-979.

Kedves, A., Rónavári, A., Kónya, Z., 2021. Long-term effect of graphene oxide on the aerobic granular sludge wastewater treatment process, Journal of Environmental Chemical Engineering, 9(1), 104853.

Khan, S., Syed, A. T., Ahmad, R., Rather, T. A., Ajaz, M., & Jan, F. A. 2010. Radioactive waste management in a hospital. International journal of health sciences, 4(1), 39.

Khanday, W. A., Ahmed, M. J., Okoye, P. U., Hummadi, E. H., Hameed, B. H., 2019.Single-step pyrolysis of phosphoric acid-activated chitin for efficient adsorption of cephalexin antibiotic, Bioresource Technology, 280, 255-259.

Kim, S., Marion, M., Jeong, B.H., Hoek, E.M.V., 2006. Crossflow membrane filtration of interacting nanoparticle suspensions. Journal of Membrane Science, 284, 361–372.

Kim, K. S., Zhao, Y., Jang, H., Lee, S. Y., Kim, J. M., Kim, K. S., Ahn, J-H., Kim, P., Choi, J-Y., Hong, B. H., 2009. Large-scale pattern growth of graphene films for stretchable transparent electrodes, Nature, 457, 706–710.

Komal, Gupta, K., Nidhi, Kaushik, A., Singhal, S., 2022. Amelioration of adsorptive efficacy by synergistic assemblage of functionalized graphene oxide with esterified cellulose nanofibers for mitigation of pharmaceutical waste, Journal of Hazardous Materials, 424, Part B, 127541.

Kovtyukhova, N. I., Ollivier, P. J., Martin, B. R., Mallouk, T. E., Chizhik, S. A., Buzaneva, E. V., 1999. Layer-by-Layer assembly of ultrathin composite films from micron–sized graphite oxide sheets and polycations, Chemistry of Materials, 11 (3), 771–778.

Kumar, N., Salehiyan, R., Chauke, V., Botlhoko, O. J., Setshedi, K., Scriba, M., Masukume, M., Ray, S. S., 2021. Top-down synthesis of graphene: A comprehensive review, FlatChem, 27, 100224.

Kumari, T. S. D., 2021. Catalytic graphitization: A bottom-up approach to graphene and quantum dots derived therefrom – A review, Materialstoday: Proceedings, 46(8), 3069-3074.

Kyzas, G. Z., Deliyanni, E. A., Bikiaris, D. N., Mitropoulos, A. C., 2018. Graphene composites as dye adsorbents: Review, Chemical Engineering Research and Design, 1 2 9, 75–88.

Lagergren, S., Svenska, B. K., 1898. On the theory of so-called adsorption of dissolved substances, The Royal Swedish Academy of Sciences Document, Band 24, 1–13.

Langmuir, I., 1916. The constitution and fundamental properties of solids and liquids, Journal of the American Chemical Society, 38 (11), 2221-2295.

Lee, L., Noh, S., Pham, N. D., Shim, J. H., 2019. Top-down synthesis of S-doped graphene nanosheets by electrochemical exfoliation of graphite: metal-free bifunctional catalysts for oxygen reduction and evolution reactions, Electrochim. Acta, 313, 1-9.

Lefebvre, O., Shi, X., Wu, C. H., Ng, H. Y. (2014). Biological treatment of pharmaceutical wastewater from the antibiotics industry. Water science and technology, 69(4), 855-861.

Lehto, J., Koivula, R., Leinonen, H., Tusa, E., Harjula, R. (2019). Removal of radionuclides from Fukushima Daiichi waste effluents. Separation & Purification Reviews, 48(2), 122-142.

Letcher, T. M., Slack, R. (2019, January). Chemicals in Waste: Household Hazardous Waste. In Waste (pp. 337-352). Academic Press.

Li, N., Wang, Z., Zhao, K., Shi, Z., Gu, Z., Xu, S., 2009. Large scale synthesis of N-doped multi-layered graphene sheets by simple arc-discharge method, Carbon 48 (1), 255–259.

Li, M-F., Liu, Y-G., Zeng, G-M., Liu, N., Liu, S-B., 2019. Graphene and graphene-based nanocomposites used for antibiotics removal in water treatment: A review, Chemosphere 226, 360-380.

Li, F-M., Liu, Y-G, Zeng, G-M., Liu, N., Liu, S-B., 2019. Graphene and graphene-based nanocomposites used for antibiotics removal in water treatment: A review, Chemosphere 226, 360380.

Li, y., Lai, Z., Huang, Z., Wang, H., Zhao, C., Ruan, G., Du, F., 2021. Fabrication of BiOBr/MoS_2/graphene oxide composites for efficient adsorption and photocatalytic removal of tetracycline antibiotics, Applied Surface Science, 550, 149342.

Lim, J. Y., Mubarak, N. M., Abdullah, E. C., Nizamuddin, S., Khalid, M., Inamuddin, 2018. Recent trends in the synthesis of graphene and graphene oxide- based nanomaterials for removal of heavy metals — A review, Journal of Industrial and Engineering Chemistry 66, 29–44.

Lin, T., Tang, Y., Wang, Y., Bi, H., Liu, Z., Huang, F., Xie, X., Jiang, M., 2013. Scotch-tape-like exfoliation of graphite assisted with elemental sulfur and graphene–sulfur composites for high-performance lithium-sulfur batteries, Energy and Environmental Science, 6, 4, 1283-1290.

Lin, Y., Xu, S., Li, J. 2013. Fast and highly efficient tetracyclines removal from environmental waters by graphene oxide functionalized magnetic particles. Chemical Engineering Journal, 225, 679-685.

Lin, Z., Karthik, P. S., Hada, M., Nishikawa, T., Hayashi, Y., 2017. Simple technique of exfoliation and dispersion of multilayer graphene from natural graphite by ozone-assisted sonication, Nanomaterials, 7 (6), 125.

Liu, J., Liu, L., Sun, D. D., 2012. Graphene oxide enwrapped Ag_3PO_4 composite: towards a highly efficient and stable visible-light-induced photocatalyst for water purification. Catalysis Science and Technology, 2, 2525-2532.

Liu, J., Ruffieux, P., Feng, X., Müllen, K., Fasel, R., 2014. Cyclotrimerization of arylalkynes on Au(III), Chemical Communications, 50, 11200-11203.

Ma, F., Li, Z., Zhao, H., Geng, Y., Zhou, W., Li, Q., Zhang, L., 2017. Potential application of graphene oxide membranes for removal of Cs(I) and Sr(II) from high level-liquid waste, Separation and Purification Technology, 188, 523-529.

Ma, Z., Wu, H., Zhang, K., Xu, X., Wang, C., Zhu, W., & Wu, W. 2018. Long-term low dissolved oxygen accelerates the removal of antibiotics and antibiotic resistance genes in swine wastewater treatment. Chemical Engineering Journal, 334, 630-637.

Ma, C., Yang, S., Cheng, Y., Xing, Z. 2020. Study on preparation of magnetic graphene oxide composites and its adsorption performance for Cr3+ in tannery wastewater. Liaoning Chemical Industry, 49(09), 1072–1074.

Mohamed, K. A., Ahmed, E. S., Mohamed, A., Mohamed, M., El-Desoky, Senentxu, L. M., 2021. Silver-doped cadmium selenide/graphene oxide-filled cellulose acetate nanocomposites for photocatalytic degradation of malachite green toward wastewater treatment, ACS Omega, 6, 23129-23138.

Mahmoodi, N. M., Oveisi, M., Bakhtiari, M., Hayati, B., Shekarchi, A. A., Bagheri, A., Rahimi, S., 2019. Environmentally friendly ultrasound-assisted synthesis of magnetic zeolitic imidazolate framework - Graphene oxide nanocomposites and pollutant removal from water, Journal of Molecular Liquids, 282, 115-130.

Mohan, V. B., Liu, D., Jayaraman, K., Stamm, M., Bhattacharyya, D., 2016. Improvements in electronic structure and properties of graphene derivatives, Advanced Materials Letter, 7 (6), 421–429.

Moreira, V. R., Lebron, Y. A. R., da Silva, M. M., Santos, L. V., Jacob, R. S., de Vasconcelos, C. K. B., Viana, M. M., 2020. Graphene oxide in the remediation of norfloxacin from aqueous matrix: simultaneous adsorption and degradation process, Environmental Science and Pollution Research, 27, 34513–34528.

Mortazavi, M., Baghdadi, M., Javadi, N. H. S., Torabian, A. 2019. The black beads produced by simultaneous thermal reducing and chemical bonding of graphene oxide on the surface of amino-functionalized sand particles: Application for PAHs removal from contaminated waters, Journal of Water Process Engineering, 31, 100798.

Mu, W., Qianhong, Q., Hu, R., Li, X., Wei, H., Jian, Y. 2017. Porous three-dimensional reduced graphene oxide merged with WO_3 for efficient removal of radioactive strontium, Applied Surface Science, 423, 1203-1211.

Muralikrishna, I. V., Manickam, V., 2017. Chapter One—Introduction. Environmental Management, 1-4.

Nagarajan, L., Saravanan, P., Kumaraguru, K., Joo, S-W., Vasseghian, Y., Rajeshkannan, R., Rajasimman, M. 2022. Synthesis of magnesium nanocomposites decked with multilayer graphene (MG) and its application for the adsorptive removal of pollutant Chemosphere, 298, 134121.

Nam, S.W., Jung, C., Li, H., Yu, M., Flora, J.R., Boateng, L.K., Her, N., Zoh, K.D., Yoon, Y., 2015. Adsorption characteristics of diclofenac and sulfamethoxazole to graphene oxide in aqueous solution. Chemosphere, 136, 20-26.

Nayak, L., Rahaman, M., Moukwa, M., 2022 Synthesis/preparation and surface modification/functionalization of graphene, and concept of nanocomposites, Polymer Nanocomposites Containing Graphene, 1-44.

Ninwiwek, N., Hongsawat, P., Punyapalakul, P., Prarat, P., 2019. Removal of the antibiotic sulfamethoxazole from environmental water by mesoporous silica-magnetic graphene oxide nanocomposite technology: Adsorption characteristics, coadsorption and uptake mechanism, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 580 (5), 123716.

Niu, L., Coleman, J. N., Zhang, H., Shin, H., Chhowalla, M., Zheng, Z., 2016. Production of two-dimensional nanomaterials via liquid-based direct exfoliation, Small 12 (3), 272–293.

Nodeh, M. K. M., Soltani, S., Shahabuddin, S., Rashidi Nodeh, H., Sereshti, H. 2018. Equilibrium, kinetic and thermodynamic study of magnetic polyaniline/graphene oxide-based nanocomposites for ciprofloxacin removal from water. Journal of Inorganic and Organometallic Polymers and Materials, 28(3), 1226-1234.

Novoselov, K. S., Jiang, D., Schedin, F., Booth, T., Khotkevich, V., Morozov, S., Two-dimensional atomic crystals, 2005. Proceedings of the National Academy *of* Sciences of the United States of America 102 (30), 10451-10453.

Obayomi, K. S., Lau, S. Y., Danquah, M., Chiong, T., Takeo, M., 2022. Advances in graphene oxide based nanobiocatalytic technology for wastewater treatment, Environmental Nanotechnology, Monitoring & Management, 17, 100647.

Pal, P., 2018. Treatment and disposal of pharmaceutical wastewater: toward the sustainable strategy. Separation & Purification Reviews, 47(3), 179-198.

Pan, X., Zhao, Y., Liu, S., Korzeniewski, C. L., Wang, S., Fan, Z., 2012. Comparing graphene-TiO_2 nanowire and graphene-TiO_2 nanoparticle composite photocatalysts, ACS Applied Materials and Interfaces, 4(8), 3944-3950.

Paredes, J. I., Villar-Rodil, S., Fernandez-Merino, M. J., Guardia, L., Martinez-Alonso, A., Tascon, J. M. D., 2011. Environmentally friendly approaches toward the mass production of processable graphene from graphite oxide, J. Mater. Chem. 21 (2), 298–306.

Park, C.M., Wang, D., Han, J., Heo, J., Su, C., 2019. Evaluation of the colloidal stability and adsorption performance of reduced graphene oxide-elemental silver/ magnetite nanohybrids for selected toxic heavy metals in aqueous solutions, Applied Surface Science, 471, 8-17.

Patel, H. K., Kalaria, R. K., okhakar, P. H., Mehta, A. A., Patel, H. V., 2022. An application of bionanotechnology in removal of emerging contaminants from pharmaceutical waste, Development in Wastewater Treatment Research and Processes, 371-384.

Patil, P.M., Mahamuni, P.P., Shadija, P.G., 2019. Conversion of organic biomedical waste into value added product using green approach. Environmental Science Pollution Research, 26, 6696–6705.

Peng, W., Li, H., Liu, Y., Song, Sh., 2017. A review on heavy metal ions adsorption from water by graphene oxide and its composites. Journal of Molecular Liquids, 230, 496–504.

Peng, J., Yan, J., Chen, Q., Jiang, X., Yao, G., Lai, B. 2018. Natural mackinawite catalytic ozonation for N, N-dimethylacetamide (DMAC) degradation in aqueous solution: Kinetic, performance, biotoxicity and mechanism. Chemosphere, 210, 831-842.

Perera, S. D., Mariano, R. G., Vu, K., Nour, N., Seitz, O., Chabal, Y., Balkus, K. J., 2012., Hydrothermal synthesis of graphene-TiO_2 nanotube composites with enhanced photocatalytic activity, ACS Catalysis, 2(6), 949-956.

Pervaiz, E., Farrukh, S., Yang, M. 2022. Catalytic adsorptive removal of toxic compounds from water using motifs of Ce doped Co_3O_4/RGO nanohybrids. Cleaner Engineering and Technology, 7, 100417.

Phoon, B. L., Ong, C. C., Saheed, M. S. M., Show, P. L., Chang, J-S., Ling, T. C., Lami, S. S., Juan, J. C. 2020. Conventional and emerging technologies for removal of antibiotics from Wastewater, Journal of Hazardous Materials, 122961.

Pi, Y., Ma, L., Zhao, P., Cao, Y., Gao, H., Wang, C., Li, Q., Dong, S. Sun, J., 2018. Facile green synthetic graphene-based Co-Fe Prussian blue analogues as an activator of peroxymonosulfate for the degradation of levofloxacin hydrochloride. Journal of colloid and interface science, 526, pp.18-27.

Priya, B., Raizada, P., Singh, N., Thakur, P., Singh, P., 2016.. Adsorptional photocatalytic mineralization of oxytetracycline and ampicillin antibiotics using Bi_2O_3/BiOCl supported on graphene sand composite and chitosan, Journal of Colloid and Interface Science, 479, 271-283.

Priyadharshini, S. D., Manikandan, S., Kiruthiga, R., Rednam, U., Babu, P. S., Subbaiya, R., Karmegam, N., Kim, W., Govarthanan, M., 2022. Graphene oxide-based nanomaterials for the treatment of pollutants in the aquatic environment: Recent trends and perspectives – A review, Environmental Pollution, 306, 119377.

Qiao, D., Li, Z., Duan, J., He, X. 2020. Adsorption and photocatalytic degradation mechanism of magnetic graphene oxide/ZnO nanocomposites for tetracycline contaminants. Chemical Engineering Journal, 400, 125952.

Qin, Y., Luo, J., Zhao, Y., Yao, C., Li, Y., An, Q., Xiao, Z., Zhai, S., 2022. Dual-wastes derived biochar with tailored surface features for highly efficient p-nitrophenol adsorption, Journal of Cleaner Production, 353, 131571.

Qu, H., Xiao, X., Han, Z., Hu, M., Shen, S., Yang, L., Jia, F., Wang, T., Ye, Z., Sun, W., Wang, Y., Huang, L., Zhu, Z., Servati, P., Tang, J., Chen, J., 2022. Graphene Oxide Nanofiltration Membrane Based on Three-Dimensional Size-Controllable Metal–Organic Frameworks for Water Treatment, ACS Applied Nano Materials, 5(4), 5196–5207.

Radmehr, S., Sabzevari, M. H., Ghaedi, M., Azqhandi, M. H. A., Marahel, F., 2021. Adsorption of nalidixic acid antibiotic using a renewable adsorbent based on Graphene oxide from simulated wastewater, Journal of Environmental Chemical Engineering, 9(5), 105975.

Rajabi, M., Moradi, O., Sillanpää, M., Zare, K., Asiri, A. M., Agarwal, S., Gupta, V. K., 2019. Removal of toxic chemical ethidium monoazide bromide using graphene oxide: Thermodynamic and kinetics study, Journal of Molecular Liquids, 293. 111484.

Ramalingam, G., Perumal, N., Priya, A. K., Rajendran, S., 2022. A review of graphene-based semiconductors for photocatalytic degradation of pollutants in wastewater, Chemosphere, 300, 134391.

Reddy, Y. V. M., Shin, J. H., Palakollu, V. N., Sravani, B., Choi, C-H., Park, K., Kim, S-K., Madhavi, G., Park, J. B., Shetti, N. P., 2022. Strategies, advances, and challenges associated with the use of graphene-based nanocomposites for electrochemical biosensors, Advances in Colloid and Interface Science, 304, 102664.

Reina, A., Jia, X. T., Ho, J., Nezich, D., Son, H., Bulovic, V., Dresselhaus, M., Kong, J., 2009. Large area, few-layer graphene films on arbitrary substrates by chemical vapor deposition, Nano Letters 9 (1), 30–35.

Rokuta, E., Hasegawa, Y., Itoh, A., Yamashita, K., Tanaka, T., Otani, S., 1999. Vibrational spectra of the monolayer films of hexagonal boron nitride and graphite on faceted Ni, Surface Science, 427, 97-101.

Rostamian, R. and Behnejad, H., 2016. A comparative adsorption study of sulfamethoxazole onto graphene and graphene oxide nanosheets through equilibrium, kinetic and thermodynamic modeling. Process Safety and Environmental Protection, 102, 20-29.

Saleh, H. E. D. M. (2016). Introductory chapter: introduction to hazardous waste management. Management of Hazardous Wastes, 1.

Salvatierra, R. V., Souza, V. H. R., Matos, C. F., Oliveira, M. M., Zarbin, A. J. G., 2015.Graphene chemically synthesized from benzene at liquid–liquid interfaces, Carbon, 93, 924-932.

Santos, J. L., Aparicio, I. Alonso, E., 2007. Occurrence and risk assessment of pharmaceutically active compounds in wastewater treatment plants. A case study: Seville city (Spain), Environ. Int., 33: 596-601.

Santos, E. J., Kaxiras, E., 2013. Electric-field dependence of the effective dielectric constant in graphene, Nano Letter, 13 (3), 898-902.

Saravanan, A., SenthilKumar, P., Srinivasan, S., Jeevanantham, S., Vishnu, M., Amith, K. V., Sruthi, R., Saravanan, R., Vo, D-V, N., 2022.Insights on synthesis and applications of graphene-based materials in wastewater treatment: A review, Chemosphere, 298, 134284.

Sehar, S., Sher, F., Zhang, S., Khalid, U., Sulejmanović, J., Lima, E. C., 2020. Thermodynamic and kinetic study of synthesized graphene oxide-CuO nanocomposites: A way forward to fuel additive and photocatalytic potentials, Journal of Molecular Liquids, 313, 113494.

Shahzad, A., Mian, A. H., Khan, M. A., Ali, K., & Hamid, T. 2021. The emergence of different bacterial pathogens in hospital wastewater samples and their antibiotic resistance pattern. Materials Circular Economy, 3(1), 1-8.

Shi, W., Wang, Li., Wang, J., Sun, H., Shi, Y., Guo, F., Lu, Y., 2022. Magnetically retrievable CdS/reduced graphene oxide/$ZnFe_2O_4$ ternary nanocomposite for self-generated H_2O_2 towards photo-Fenton removal of tetracycline under visible light irradiation, Separation and Purification Technology, 292, 120987.

Shin, H. J., Kim, K. K., Benayad, A., Yoon, S-M., Park, H. K., Jung, I-S., Jin, M. H., Jeong, H-K., Kim, J. M., Choi, J-Y., Lee, Y. H., 2009. Efficient reduction of graphite oxide by sodium borohydride and its effect on electrical conductance, Advanced Functional Materials, 19 (12), 1987-1992.

Sohal, B., Bhat, S. A., Vig, A., P., 2021. Vermiremediation and comparative exploration of physicochemical, growth parameters, nutrients and heavy metals content of biomedical waste ash via ecosystem engineers *Eisenia fetida*, Ecotoxicology and Environmental Safety, 227, 112891.

Somasekaran, B., Thirunarayanaswamy, A., Palanivel, I., 2022. Synthesis of Graphene and fabrication of Aluminium-Gr_p nanocomposites: A review, 50(5), 2436-2442.

Song, W., Yang, T., Wang, X., Sun, Y., Ai, Y., Sheng, G., Hayat, T., Wang, X., 2016. Experimental and theoretical evidence for competitive interactions of tetracycline and sulfamethazine with reduced graphene oxides. Environmental Science: Nano, 3, 1318-1326.

Song, D., Mahajan, A., Secor, E. B., Hersam, M. C., Francis, F., Frisbie, C. D., 2017. High-resolution transfer printing of graphene lines for fully printed, flexible electronics, ACS Nano, 11 (7), 7431-7439.

Song, C., Guo, B. B., Sun, X. F., Wang, S. G., Li, Y. T. 2019. Enrichment and degradation of tetracycline using three-dimensional graphene/MnO2 composites. Chemical Engineering Journal, 358, 1139-1146.

Stankovich, S., Dikin, D. A., Piner, R. D., Kohlhaas, K. A., Kleinhammes, A., Jia, Y., 2007. Synthesis of graphene-based nanosheets via chemical reduction of exfoliated graphite oxide, Carbon 45 (7), 1558–1565.

Staudenmaier, L., 1898. Verfahren zur darstellung der graphits€aure. Ber Deutsche Chem. Ges. 31, 1481-1487.

Su, H., Ye, Z., Hmidi, N. 2017. High-performance iron oxide–graphene oxide nanocomposite adsorbents for arsenic removal. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 522, 161-172.

Suksompong, T., Thongmee, S., Sudprasert, W., 2021. Efficacy of a Graphene Oxide/Chitosan Sponge for Removal of Radioactive Iodine-131 from Aqueous Solutions, Life, 11(7), 721.

Tabish, S. A., 2005. Ecohealth: management of biomedical waste. Hospital Infection Control: Conceptual Framework. Academa Publishers, 139-145.

Tang, H., Ehlert, G. J., Lin, Y., Sodano, H. A., 2011. Highly efficient synthesis of graphene nanocomposites, Nano Letters, 12 (1), 84–90.

Tang, Y., Guo, H., Xiao, L., Yu, S., Gao, N., Wang, Y. 2013. Synthesis of reduced graphene oxide/magnetite composites and investigation of their adsorption performance of fluoroquinolone antibiotics. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 424, 74-80.

Tang, Y., Liu, X., Ma, C., Zhou, M., Huo, P., Yu, L., Pan, J., Shi, W., Yan, Y., 2015. Enhanced photocatalytic degradation of tetracycline antibiotics by reduced graphene oxide CdS/ZnS heterostructure photocatalysts, New Journal of Chemistry, 39, 5150-5160.

Tayel, A., Ramadan, A. R., El Seoud, O. A., 2018. Titanium dioxide/graphene and titanium dioxide/graphene oxide nanocomposites: Synthesis, characterization and photocatalytic applications for water decontamination, Catalysts, 8 (11), 491.

Tong, A. Y.C. Peake, B. M. and Braund, R., 2011. Disposal practices for unused medications around the world. Environment International, 37(1), 292–298.

Ullah, T., Gul, K., Khan, H., Ara, B., Zia, T. U. H. 2022. Efficient removal of selected fluoroquinolones from the aqueous environment using reduced magnetic graphene oxide/polyaniline composite. Chemosphere, 133452.

Vellinga, A. Cormican, S. Driscoll, J. Furey, M. O'Sullivan, M. and Cormican, M. (2014) Public practice regarding disposal of unused medicines in Ireland. M. Sci. Total Environ., 478: 98–102.

Verma, S., Nadagouda, M. N. 2021. Graphene-Based Composites for Phosphate Removal. ACS omega, 6(6), 4119-4125.

Verma, M., Lee, I., Oh, J., Kumar, V., Kim, H., 2022. Synthesis of EDTA-functionalized graphene oxide-chitosan nanocomposite for simultaneous removal of inorganic and organic pollutants from complex wastewater Chemosphere, 287, 132385.

Wang, G., Yang, J., Park, J., Gou, X., Wang, B., Liu, H., 2008. Facile synthesis and characterization of graphene nanosheets, Journal of Physical Chemistry C 112 (22), 8192–8195.

Wang, X. Song, L. Yang, H. Xing, W. Candela, B. Hu, Y. 2012. Simultaneous reduction and surface functionalization of graphene oxide with POSS for reducing fire hazards in epoxy composites, Journal of Material Chemistry, 22 (41), 22037–22043.

Wang, F., Yang, T., Wang, H., Song, Q., Tan, F., Cao, Y., 2016. Removal of ciprofloxacin from aqueous solution by a magnetic chitosan grafted graphene oxide composite, Journal of Molecular Liquids, 222, 188-194.

Wang, D., Zhang, G., Zhou, L., Wang, M., Cai, D., Wu, Z., 2017. Synthesis of a multifunctional graphene oxide-based magnetic nanocomposite for efficient removal of Cr (VI). Langmuir 33, 7007-7014.

Wang K, Pang J, Li L, Zhou S, Li Y, Zhang T. 2018. Synthesis of hydrophobic carbon nanotubes/reduced graphene oxide composite films by flashlight irradiation. Frontiers of Chemical Science and Engineering, 12(3), 376-82.

Wang, K., Wu, J., Zhu, M., Zheng, Y-Z, Tao, X., 2020. Highly effective pH-universal removal of tetracycline hydrochloride antibiotics by UiO-66-$(COOH)_2$/GO metal–organic framework composites, Journal of Solid State Chemistry, 284, 121200.

Wang, J., Zhang, J., Han, L., Wang, J., Zhu, L., Zeng, H., 2021a. Graphene-based materials for adsorptive removal of pollutants from water and underlying interaction mechanism, Advances in Colloid and Interface Science 289, 102360.

Wang, J., Li, X., Tang, L., Ma, X., Lu, L., Chen, Y., Zhong, C. 2021b. Synthesis Approaches to Magnetic Graphene Oxide and Its Application in Water Treatment: A Review. Water, Air, & Soil Pollution, 232(8), 1-16.

Wang, J., Zang, L., Wang, L., Tian, Y., Yang, Z., Yue, Y., Sun, L., 2022. Magnetic cobalt ferrite/reduced graphene oxide (CF/rGO) porous balls for efficient photocatalytic degradation of oxytetracycline, Journal of Environmental Chemical Engineering, 10(5), 108259.

Wu, T., Liu, S., Li, H., Wang, L., Sun, X., 2011. Production of reduced graphene oxide by UV irradiation, Journal of Nanoscience and Nanotechnology 11 (11), 10078–10081.

Wu, S., Zhao, X., Li, Y., Du, Q., Sun, J., Wang, Y., Wang, X., Xia, Y., Wang, Z., Xia, L., 2013. Adsorption properties of doxorubicin hydrochloride onto graphene oxide: equilibrium, kinetic and thermodynamic Studies, Materials, 6, 2026-2042.

Xiao, R., Wang, S., Ibrahim, M. H., Abdu, H. I., Shan, D., Chen, J., Lu, X. 2019. Three-dimensional hierarchical frameworks based on molybdenum disulfide-graphene oxide-supported magnetic nanoparticles for enrichment fluoroquinolone antibiotics in water. Journal of Chromatography A, 1593, 1-8.

Xing, H.T., Chen, J.H., Sun, X., Huang, Y.H., Su, Z.B., Hu, S.R., Weng, W., Li, S.X., G H, X., 2015. NH_2-rich polymer/graphene oxide use as a novel adsorbent for removal of Cu(II) from aqueous solution. Chemical Engineering Journal, 263, 280-289.

Xu, X., Ding, X., Yang, X., Wang, P., Li, S., Lu, Z., Chen, H., 2019. Oxygen vacancy boosted photocatalytic decomposition of ciprofloxacin over Bi_2MoO_6: Oxygen vacancy engineering, biotoxicity evaluation and mechanism study, Journal of Hazardous Material, 364, 691-699.

Xu, M., Wang, Y., Ha, E., Zhang, H., Li, C., 2021. Reduced graphene oxide/$Bi_4O_5Br_2$ nanocomposite with synergetic effects on improving adsorption and photocatalytic activity for the degradation of antibiotics, Chemosphere, 265, 129013.

Yakout, A. A., Alshitari, W., Akhdhar, A., 2021. Synergistic effect of Cu-nanoparticles and β-cyclodextrin functionalized reduced graphene oxide nanocomposite on the adsorptive remediation of tetracycline antibiotics, Carbohydrate Polymers, 273, 118528.

Yashas, S. R., Shivaraju, H. P., McKay, G., Shahmoradi, B., Maleki, A., Yetilmezsoy, K., 2021. Designing bi-functional silver delafossite bridged graphene oxide interfaces: Insights into synthesis, characterization, photocatalysis and bactericidal efficiency, , Chemical Engineering Journal, 426, 131729.

Yan, J., Li, R., 2022. Simple and low-cost production of magnetite/graphene nanocomposites for heavy metal ions adsorption, Science of The Total Environment, 813, 152604.

Yang, K., Chen, B., Zhu, L. 2015. Graphene-coated materials using silica particles as a framework for highly efficient removal of aromatic pollutants in water. Scientific reports, 5(1), 1-12.

Yang, A., Wang, Z., Zhu, Y. 2021a. Facile preparation and highly efficient sorption of magnetic composite graphene oxide/Fe_3O_4/GC for uranium removal. Scientific Reports, 11(1), 1-10.

Yang, X, Chen, Z., Zhao, W., Liu, C., Qian, X., Zhang, M., Wei, G., Khan, F., Ng, Y. H., Ok, Y. S., 2021b. Recent advances in photodegradation of antibiotic residues in water, Chemical Engineering Journal, 405, 126806.

Yang, L., Xiao, X., Shen, S., Lama, J., Hu, M., Jia, F., Han, Z., Qu, H., Huang, L., Wang, Y., Wang, T., Ye, Z., Zhu, Z., Tang, J., Chen, J**., 2022.** Recent Advances in Graphene Oxide Membranes for Nanofiltration, ACS Applied Nano Materials,5(3), 3121–3145.

Yang, J., Shojaei, S., Shojaei, S., 2022. Removal of drugs and dye from aqueous solutions by graphene oxide: Adsorption studies and chemometrics methods, npj clean water, 5(5), 1147.

Yang, P., Yu, F., Yang, Z., Zhang, X., Ma, J., 2022. Graphene oxide modified κ-carrageenan/sodium alginate double-network hydrogel for effective adsorption of antibiotics in a batch and fixed-bed column system, Science of The Total Environment, 837, 155662.

Yazdi, G. R., Iakimov, T., Yakimova, R., 2016. Epitaxial graphene on silicon carbide: A Review of Growth and Characterization, Crystal, 6, 53.

Yi, M., Shen, Z., 2015. A review on mechanical exfoliation for the scalable production of graphene, Journal of Materials Chemistry A, 3 (22), 11700–11715.

Yu, F., Li, Y., Han, S., Ma, J. 2016. Adsorptive removal of antibiotics from aqueous solution using carbon materials, Chemosphere, 153, 365-385,

Zaied, B. K., Rashid, M., Nasrullah, M., Zularisam, A. W., Pant, D., & Singh, L. (2020). A comprehensive review on contaminants removal from pharmaceutical wastewater by electrocoagulation process. Science of the Total Environment, 726, 138095.

Zakrzewska-Trznadel, G., 2013. Advances in membrane technologies for the treatment of liquid radioactive waste. Desalination, 321, 119-130.

Zanin, E., Scapinello, J., Oliveira, M.D., Maria, J., Mello, M.D., Antonio, M., Oliveira, J.V., Dal, J., 2017. Adsorption of heavy metals from wastewater graphic industry using clinoptilolite zeolite as adsorbent. Process Safety and Environmental Protection. 105, 194-200.

Zhang, Y., Small, J. P., Pontius, W. V., Kim, P., 2005. Fabrication and electric-field-dependent transport measurements of mesoscopic graphite devices, Applied Physics. Letters. 86, 073104.

Zhang, X., Jiang, X., Zhang, K., Mao, L., Luo, J., Chi, C., Chan, H. S. O., Wu, J., 2010. Synthesis, Self-Assembly, and Charge Transporting Property of Contorted Tetrabenzocoronenes, Journal of Organic Chemistry, 23, 8069-8077.

Zhang, Y., Jiao, Z., Hu, Y., Lv, S., Fan, H., Zeng, Y., Hu, J., Wang, M., 2017. Removal of tetracycline and oxytetracycline from water by magnetic Fe3O4@graphene, Environmental Science and Pollution Research, 24, 2987-2995.

Zhang, R., Li, Y., Cai, Y., Han, Q., Zhang, T., Liu, Y., Zeng, K., Zhao, C., 2020. Photocatalytic Poly(vinylidene fluoride) membrane of Ag_3PO_4/GO/APTES for water treatment, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 597, 124779.

Zhang, Z., Xiao, X., Zhou, Y., Huang, L., Wang, Y., Rong, Q., Han, Z., Qu, H., Zhu, Z., Xu, S., Tang, J., Jun Chen, 2021. Bioinspired Graphene Oxide Membranes with pH-Responsive Nanochannels for High-Performance Nanofiltration ACS Nano, 15(8), 13178–13187.

Zhang, Y., Wang, H., Gao, K., Huang, D., Hou, L., Yang, Y., 2022a. Efficient removal of Cs(I) from water using a novel Prussian blue and graphene oxide modified PVDF membrane: Preparation, characterization, and mechanism, Science of The Total Environment, 838 (4), 156530.

Zhang, N., Ning, X., Chen, J., Xue, J., Lu, G., Qiu, H., 2022b. Photocatalytic degradation of tetracycline based on the highly reactive interface between graphene nanopore and TiO_2 nanoparticles, Microporous and Mesoporous Materials, 338, 111958.

Zheng Q-F, Guo Y, Liang Y, Shen Q. 2020. Graphene nanoribbons from electrostatic-force-controlled electric unzipping of single-and multi-walled carbon nanotubes. ACS Applied Nano Materials, 3(5), 4708-16.

Zhou, X., Zhang, J., Wu, H., Yang, H., Zhang, J., Guo, S., 2011. Reducing graphene oxide via hydroxylamine: a simple and efficient route to graphene, Journal of Physical Chemistry C 115 (24), 11957–11961.

Zhao, Y., Wang, Y., Shi, H., Liu, E., Fan, J., Hu, X., 2018. Enhanced photocatalytic activity of ZnSe QDs/g-C_3N_4 composite for Ceftriaxone sodium degradation under visible light, Material Letters, 231, 150-153.

Zhou, L., Alvarez, O.G., Mazon, C.S., Chen, L., Deng, H., Sui, M., 2016. The roles of conjugations of graphene and Ag in Ag3PO4-based photocatalysts for degradation of sulfamethoxazole, Catalysis Science and Technology, 6, 5972-5981.

Zhou, J., Fang, M., Yang, K., Lu, K., Fei, H., Mu, P., He, R., 2022. MIL-101(Cr)-NH_2/reduced graphene oxide composite carrier enhanced thermal conductivity and stability of shape-stabilized phase change materials for thermal energy management, Journal of Energy Storage, 52, 104827.

Zhu, X., Tsang, D.C., Chen, F., Li, S., Yang, X., 2015. Ciprofloxacin adsorption on graphene and granular activated carbon: kinetics, isotherms, and effects of solution chemistry. Environmental Technology, 36, 3094-3102.

Zhu, S., Xia, M., Chu, Y., Khan, M. A., Lei, W., Wang, F., Muhmood, T., Wang, A., 2018. Adsorption and Desorption of Pb(II) on L-Lysine Modified Montmorillonite and the simulation of Interlayer Structure, Applied Clay Science, 169, 40-47.

Zhu, S., Khan, M. A., Kameda, T., Xu, H., Wang, F., Xia, M., Yoshioka, T., 2022. New insights into the capture performance and mechanism of hazardous metals Cr^{3+} and Cd^{2+} onto an effective layered double hydroxide based material, Journal of Hazardous Materials, 426, 128062.

Zou, Y., Walton, A. S., Kinloch, I. A., Dryfe, R. A., 2016. Investigation of the differential capacitance of highly ordered pyrolytic graphite as a model material of graphene. Langmuir, 32 (44), 11448-11455.

Zou, S-J., Chen, Y-F., Zhang, Y., Wang, X-F., You, N., Fan, H-T., 2021. A hybrid sorbent of α-iron oxide/reduced graphene oxide: Studies for adsorptive removal of tetracycline antibiotics, Journal of Alloys and Compounds, 863, 158475.